PB88-185277

Corrective Measures for Releases to Soil from Solid Waste Management Units

Alliance Technologies Corp., Bedford, MA

Prepared for

Environmental Protection Agency, Washington, DC

Aug 85

U.S. Department of Commerce
National Technical Information Service

EPA/530-SW-88-022

GCA-TR-85-66-G

PB88-185277

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Land Disposal Branch, Office of Solid Waste
Washington, DC 20460

Contract No. 68-01-6871
Work Assignment No. 51

EPA Work Assignment Manager
George Dixon

CORRECTIVE MEASURES FOR RELEASES TO SOIL FROM SOLID WASTE MANAGEMENT UNITS

Draft Final Report

August 1985

Prepared by

Steven C. Konieczny
Lisa Farrell
Michelle M. Gosse
Barbara Myatt
Brenda Kay
Ronald Bell
Theresa Murphy
Neil M. Ram, Ph.D.

GCA CORPORATION
GCA/TECHNOLOGY DIVISION
Bedford, Massachusetts 01730

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL
INFORMATION SERVICE
SPRINGFIELD, VA. 22161

DISCLAIMER

This Draft Final Report was furnished to the Environmental Protection Agency by the GCA Corporation, GCA/Technology Division, Bedford, Massachusetts 01730, in fulfillment of Contract No. 68-01-6871, Work Assignment No. 51. The opinions, findings, and conclusions expressed are those of the authors and not necessarily those of the Environmental Protection Agency or the cooperating agencies. Mention of company or product names is not to be considered as an endorsement by the Environmental Protection Agency.

50272-101

REPORT DOCUMENTATION PAGE	**1. REPORT NO.** EPA/530-SW-88-022	**2.**	**3. Recipient's Accession No.** PB88-185277/AS

4. Title and Subtitle

Corrective measures for releases to soil from solid waste management units

5. Report Date

Aug. 85

6.

7. Author(s)

S.C. Konieczny

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

GCA Corp.
GCA/Technology Division
Bedford, MA 01730

10. Project/Task/Work Unit No.

WA 51

11. Contract(C) or Grant(G) No.

(C) 68-01-6871

(G)

12. Sponsoring Organization Name and Address

U.S. Environmental Protection Agency
Office of Solid Waste
401 M Street, SW
Washington, D.C. 20460

13. Type of Report & Period Covered

Draft Final Report

14.

15. Supplementary Notes

Resource Conservation and Recovery Act

16. Abstract (Limit: 200 words)

Upon discovery of a release from a solid waste management unit at a RCRA facility, a complete site investigation should be performed to determine nature and extent of the release. Once the release and its extent has been characterized, and determined to be a threat to human health or the environment, corrective measures must be implemented. The draft final report discusses the various types of removal/containment (includes disposal) and treatment technologies which are applicable to remediation of releases to soils.

17. Document Analysis a. Descriptors

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement RELEASED UNLIMITED	**19. Security Class (This Report)** Unclassified	**21. No. of Pages**
	20. Security Class (This Page) Unclassified	**22. Price**

(See ANSI–Z39.18) See Instructions on Reverse

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

CONTENTS

Figures iv
Tables v

1. Introduction 1-1
    Background 1-1
    Definition/Identification of Solid Waste Management Units 1-2
    Identifying Releases to Soils 1-5
2. Assessing the Need for Corrective Measures 2-1
    Introduction 2-1
    General Approach to Risk Characterization 2-2
    Summary 2-7
3. Overview of Corrective Measures 3-1
    General 3-1
    Proven Technologies 3-5
    Imminent Technologies 3-42
4. Case Studies 4-1
    Introduction 4-1
    Fairchild Republic Company - Hagerstown, Maryland 4-4
    Whitmoyer Laboratories - Myerstown, Pennsylvania 4-9
    Enterprise Avenue - Philadelphia, Pennsylvania 4-12
    Frontenac Site - Frontenac, Missouri 4-15
    Crystal Chemical - Houston, Texas 4-19
    Silresim - Lowell, Massachusetts 4-22
5. Recommendations on how to Select and Implement Corrective Measures 5-1
    Introduction 5-1
    Important Considerations in Selecting Corrective Measures for Releases to Soils 5-5
    Summary 5-18
    Case Study Example 5-22
References R-1

Appendices

A. Fate and Transport A-1
B. Exposure Assessment B-1

FIGURES

Number Page

4-1 Worksheet for screening case studies. 4-2

4-2 Outline for case studies write-up 4-6

TABLES

Number Page

3-1 Removal (Containment)/Treatment Technologies. 3-2

3-2 Summary of Proven Removal/Treatment Technologies. 3-3

3-3 Unit Costs - Excavation of Uncontaminated Soil. 3-7

3-4 Capping/Surface Sealing Materials 3-10

3-5 Capping/Surface Sealing Unit Costs. 3-13

3-6 Modification of Soil Parameters 3-20

3-7 Compounds or Classes of Compounds that Have Been (or could be) Degraded by Commercially Available Microbial Augmentation Productions 3-24

3-8 Micro-organisms Known to Metabolize Organochlorine Pesticides . 3-25

3-9 Atmospheric Reaction Rates and Residence Times of Selected Organic Chemicals 3-29

3-10 Liming Materials. 3-33

3-11 Advantages and Disadvantages Rotary Kiln Incinerator. 3-40

3-12 Advantages and Disadvantages of Fluidized-Bed Incineration. . . 3-45

3-13 Relative Oxidation Power of Oxidizing Species 3-49

3-14 Oxidation Reactivity for Organic Chemical Classes 3-51

3-15 Some Chemicals That Do Not Oxidize at Soil and Clay Surfaces. . 3-52

3-16 Chemical Groups that React with Peroxides to Form More Mobile Products. 3-52

3-17 Chemical Reductive Treatment for Degradation of Paraquat in Soil. 3-54

TABLES (continued)

Number **Page**

4-1 Types of Release(s) and Remedial Response(s) Implemented at Selected Sites. 4-5

5-1 Pertinent Issues for Selection and Implementation of Corrective Measures. 5-2

5-2 Permit Writers' Checklist 5-19

5-3 Summary of Soil Removal/Treatment/Containment (Disposal) Technologies. 5-21

SECTION 1

INTRODUCTION

BACKGROUND

The 1984 amendments to the Hazardous and Solid Waste Act (HSWA) provide the Agency with additional authorities for corrective action at facilities seeking permits, and for facilities with interim status under Section 3005(e). The amendments for corrective action address:

- continuing releases at permitted facilities (Section 206);
- corrective action beyond facility boundaries (Section 207);
- financial responsibility for corrective action (Section 208); and
- interim status corrective action orders (Section 233).

The new authorization allows EPA to require corrective action in response to a release of hazardous waste or hazardous constituents from any solid waste management unit (SWMU) to the environment, regardless of when the waste was placed in such unit. This authority addresses releases to all media, including soil.

Based on the 1984 amendments, the U.S. EPA, Office of Solid Waste (OSW), Land Disposal Branch, must develop technical guidance for permit writers to implement the "continuing releases" provision. Implementation of these new requirements will typically take place in three stages: (1) determining whether there is a release at a facility that warrants further investigation, (2) collecting additional information to define the nature and extent of the release, and (3) selecting and performing the corrective measures. This report is intended to provide guidance on selecting corrective measures in response to a hazardous constituent release to soil. Guidance is provided on parameters and criteria which should be considered in selecting a particular remedial response for specific site conditions and identified compounds.

The remainder of this section identifies and defines the various types of solid waste management units (SWMUs). It also identifies releases to soil. Section 2 discusses the need for corrective measures through review of the potential for hazardous constituents released to soil to be transported to other environmental matrices (air, surface water, ground water) and the potential risk associated with such transport to human health and the environment. Section 3 provides an overview of corrective measures including surface soil treatment technologies. Section 4 discusses case studies where releases to soil from SWMUs have occurred and identifies the corrective measures undertaken at the site to clean up the contaminated soil. The concluding section, Section 5, provides recommendations for the application of corrective measures to soil releases. Finally, Appendices A and B provide detailed information on fate and transport mechanisms, and exposure and risk assessments, as briefly described in Section 2.

DEFINITION/IDENTIFICATION OF SOLID WASTE MANAGEMENT UNITS

Congress defined the term solid waste management unit (SWMU) to include any unit at a facility "from which hazardous constituents might migrate, irrespective of whether the units were intended for the management of solid and/or hazardous wastes." SWMUs represent a broad category of waste management units of which hazardous waste management units are a subset. Under the new requirements, Subtitle D landfills and other units (at facilities seeking a RCRA permit) which primarily handle nonhazardous solid waste could be required to take corrective action if there is evidence of a release of hazardous constituents from these units. The definition of SWMU includes both active, or operating units, and inactive, or nonoperating units. This definition also includes certain units that have previously been exempted from 40 CFR Part 264 requirements, such as wastewater treatment tanks.

The new requirements also extend to spills and other releases from SWMUs that may occur during the normal operation of these units. However, spills that cannot be linked to SWMUs, such as those originating from production areas or product storage tanks, are not covered under the continuing release provision. These spills are illegal, however, under other RCRA provisions (Sobotka, 1985). The types of units included in the SWMU definition are (in alphabetical order):

- container storage areas;
- incinerators;
- landfills;
- land treatment units;
- surface impoundments;
- tanks (including 90-day accumulation tanks);
- transfer stations;
- (underground) injection wells;*
- waste handling areas;
- waste piles;
- waste recycling operations; and
- wastewater treatment tanks.

A container, as defined in 40 CFR Part 260.10, is any portable device in which a material is stored, transported, treated, disposed of, or otherwise handled. A container storage area is the location where the container resides. Container storage areas typically consist of 55-gallon drums, but may vary in size. These areas usually include a spill containment system, typically a diked area above a low permeable barrier that underlies the storage area, and sometimes include a cover to shed precipitation.

---

*Underground injection wells are not discussed in the body of this report. By virtue of their operation, they are not as susceptible to release to soil as other SWMUs since potential releases occur only during equipment failure or waste spilling prior to injection into the subsurface. A detailed discussion of the regulatory status and the potential and cause of release from underground injection wells is provided in the Appendix of the draft report entitled "Corrective Measures for Releases to Ground Water from Solid Waste Management Units", prepared by GCA/Technology Division, August 1985.

An incinerator, as defined in 40 CFR Part 260.10, is an enclosed device using controlled flame combustion, the primary purpose of which is to thermally break down hazardous waste. Examples of incinerators are rotary kiln, fluidized bed, and liquid injection incinerators.

A landfill, as defined in 40 CFR Part 260.10, is a disposal facility or part of a facility where hazardous waste is placed in or on land and which is not a land treatment facility, a surface impoundment, or an injection well. This facility typically consists of wastes placed on a liner system to collected liquids draining from waste and includes a similar liner system (cover) on top of the waste to prevent incident precipitation from entering the waste.

A land treatment facility, as defined in 40 CFR Part 260.10, is a facility or part of a facility at which hazardous waste is applied onto or incorporated into the soil surface; such facilities are disposal facilities if the waste will remain after closure. Land treatment involves degradation of organic compounds through physiochemical biologic degradation. Nutrient and biological seeding frequently occurs with aeration of the soil/waste mixture by rototilling, plowing or harrowing.

A surface impoundment or impoundment, as defined in 40 CFR Part 260.10, means a facility or part of a facility which is a natural topographic depression, manmade excavation, or diked area formed primarily of earthen materials (although it may be lined with manmade materials), which is designed to hold an accumulation of liquid wastes or wastes containing free liquids, and which is not an injection well. Examples of surface impoundments are holding, storage, settling, and aeration pits, ponds, and lagoons.

A tank, as defined in 40 CFR Part 260.10, is a stationary device, designed to contain an accumulation of hazardous waste which is constructed primarily of nonearthen materials (e.g., wood, concrete, steel, plastic) which provide structural support.

A transfer facility, as defined in 40 CFR Part 260.10, is any transportation related facility including loading docks, parking areas, storage areas, and other similar areas where shipments of hazardous waste are held during the normal course of transportation.

Waste handling areas include container filling and emptying areas, and transfer locations (e.g. from trucks to tanks) associated with all waste management facilities. Waste handling areas are usually associated with waste transfer, such as solvent reclamation staging, incineration charging, or transfer from tank truck to tank, or drum storage area to trucks.

A (waste) pile, as defined in 40 CFR Part 260.10, is any noncontainerized accumulation of solid, nonflowing hazardous waste that is used for treatment or storage. This facility typically consists of wastes placed on a liner system to collect liquids draining from the waste.

Waste recycling operations are areas where operations involving the processing of waste materials for recovery are undertaken.

A wastewater treatment unit, as defined in 40 CFR Part 260.10, is a device which: (1) is part of a wastewater treatment facility which is subject to regulation under either Section 402 or Section 307(b) of the Clean Water Act; (2) receives and treats or stores an influent wastewater which is a hazardous waste as defined in 40 CFR Part 261.3, or generates and accumulates a wastewater treatment sludge which is a hazardous waste as defined in 40 CFR Part 261.3, or treats or stores a wastewater treatment sludge which is a hazardous waste as defined in 40 CFR Part 261.3, and (3) meets the definition of tank in 40 CFR Part 260.10 (as previously discussed).

IDENTIFYING RELEASES TO SOILS

Prior to implementation of a corrective measure at a SWMU, a release to soil must be identified and its extent characterized. "Contaminated soils" can be defined as affected soils found between the ground surface and the mean high ground-water table. These soils are affected by a "release" which is defined to include any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing into the environment, but excludes permitted discharges or releases.

Contamination in soils can be discovered in a variety of ways. If contamination is uncovered through ground water sampling and analysis at a RCRA facility, there is a possibility that a release from a solid waste management unit (SWMU) has migrated through the soils and into the ground water, thus impacting soils. Surface water sampling and analysis could also reveal a release from a SWMU that has contaminated soils and made its way via surface runoff into various surface water bodies.

Visual observations during normal inspections, or if ordered by the EPA, may reveal evidence of a release in the area of a SWMU. Dead or dying trees, general vegetative stress and obvious signs, such as substrates found in surface soils or highly discolored soils should be investigated as a sign of release. Once suspected, soil sampling can be performed at various depths to determine the extent of the contamination. For example, the hazardous constituent type, migration rate, lateral and vertical extent, and impact on ground water should be determined. Also, during inspections the lack of physical integrity of a SWMU may indicate the need for sampling to determine if a release has occurred. Examples of this may be the poor quality of a tank or deterioration in a container storage area which may make these SWMUs more susceptible to such release as leakage. Additionally, design characteristics of various disposal units may make them more susceptible to a release. For example, single-lined or unlined landfills may be more likely to have a release than some other units.

Electromagnetic methods, ground penetrating radar, shallow geothermic and remote sensing are other techniques often used to define a hazardous constituent ground-water plume. These methods may also aid in the selection of appropriate areas for soil sampling.

Once a release is discovered and its type and extent determined, some type of corrective action may be necessary. There is no definition as to the quantity of a release that represents a safe level in soils. However, if there is a potential adverse impact to human health, welfare, or the environment, then some corrective measure must be undertaken to ensure that the impact is minimized or eliminated. The following section assesses the need for and the extent of corrective measures necessary for releases to soil.

SECTION 2

ASSESSING THE NEED FOR CORRECTIVE MEASURES

INTRODUCTION

Prior to selecting and implementing corrective measures for releases to soils, a needs assessment should be conducted. The assessment of the need for corrective measures under RCRA is based on protection of human health and the environment. In the case of releases to soil, a standard for the protection of human health and the environment is not currently available. In the interim, the relevant and applicable standards for corrective action provided in the CERCLA feasibility guidance should be met.

The assessment of the need for corrective measures should define facility conditions and the extent of hazardous constituent release, identify the goal of corrective measures, assist in the selection of corrective measures and establish a time frame for implementation of corrective measures. The assessment follows a stepwise process including the following six components: source characterization; extent of contamination; fate and transport; exposure assessment; hazard (toxicity) assessment and characterization. Each of the components is discussed briefly below with emphasis on the assessment of releases of hazardous constituents to soil from a SWMU. Information essential to each component is presented in outline form for easy reference and is comparable to a checklist.

Detailed procedures for the assessment of transport and fate are presented in Appendix A of this report. Procedures for performing exposure assessment are detailed in Appendix B. Appendix B also contains additional information on hazard assessment and risk characterization; however, it should be recognized that the subjective aspects of hazard and risk assessment should only be performed by a trained toxicologist.

GENERAL APPROACH TO RISK CHARACTERIZATION

Description of Facility Area

The first step in the needs assessment is to delineate the study area and characterize the geophysical conditions that define the facility. Combined with nearby land use patterns, this information provides a general description of the area and population activity at or near the facility. Such information can be helpful in identifying localized areas of potential concern, both as sources of hazardous constituent release and hazardous constituent exposure. The information required to adequately describe the facility or study area should include:

1. The geographic setting:
    a. local topography;
    b. hydrological and geological setting;
    c. ground and surface water flow; and
    d. soil types.
2. The meteorological conditions with particular emphasis on:
    a. seasonal variation;
    b. episodic events; and
    c. climatic factors that may affect the transport and fate of chemicals.

These parameters give an indication of the potential importance of air, water and land (both sediment and soils) in both the transport and fate of chemical pollutants.

3. The land use patterns including:
    a. industrial - heavy/light;
    b. residential;
    c. agricultural;
    d. recreational; and
    e. wetlands and/or other protected ecosytems.

Extent of Contamination

The next step in the needs assessment process identifies and determines, to the extent possible, the hazardous constituents present and the concentrations of hazardous constituents in the soil medium. To determine the extent of contamination the following information should be obtained:

1. The identification of the hazardous constituents released at the facility by:
    a. source of contamination; and
    b. location of release.
2. The concentrations of the constituents observed within the soil medium.
3. The location (receptor sites) and chemical form of the constituents to which exposure occurs.
4. References to the analytical methodology/models used and QA/QC documentaion (particularly significant for enforcement activities).

Transport and Fate

The purpose of this part of the needs assessment is to describe and quantify, when possible, the potential for migration of hazardous constituents. This includes determining the potential for intermedia and intramedia transport and transformation and predicting or estimating the direction and magnitude of constituent migration. This can be accomplished by determining:

1. The chemical and physical properties of the released hazardous constituents including:
    a. solubility;
    b. Henry's Law Constant;
    c. octanol/water partition coefficient;
    d. vapor pressure; and
    e. soil/sediment adsorption coefficients.

2. The completed transport and fate section should characterize the hazardous constituents released at a facility by:

   a. the chemical form of each constituent to which exposure occurs;

   b. the potential chemical, physical and biological partitioning of the constituents in various media; and

   c. the reactive pathways that affect migration of the hazardous constituents in the facility area including:

      1) adsorption and desorption processes,
      2) volatilization,
      3) degradation/decomposition rates,
      4) photolysis,
      5) oxidation,
      6) precipitation,
      7) hydrolysis,
      8) complexation,
      9) half-lives.

3. The intermedia and intramedia transport and transformation of constituents including:

   a. the potential for volatilization from soil to air;

   b. the potential for leaching from soil to ground water/surface water; and

   c. the potential for adsorption to soil and subsequent movement in air as fugitive dusts or via overland flow with surface run-off.

Exposure Evaluation

The purpose of this step of the needs assessment is to identify actual or potential pathways and routes of exposure, characterize the populations exposed and determine the extent of the exposure. Depending on the needs of the facility assessment and the data available, this exposure evaluation may be performed either as a qualitative or quantitative assessment. To accomplish this:

1. The location and magnitude of hazardous constituent release to soil should be identified and quantified.

2. The constituent releases to soil at the facility should be characterized to the extent possible by:

    a. identifying all hazardous constituents;

    b. quantifying the chemical loading into the receiving medium (soil); and

    c. identifying and predicting the chemical fate of hazardous constituent releases - focusing on intermedia and intramedia pathways.

3. The exposed populations must be characterized:

    a. by age and by demographics (e.g. size and distribution);

    b. by subpopulations at special health risk; and

    c. by location and distance from the facility.

4. The potential exposure points must be identified for both human and non-human populations by identifying:

    a. the likely pathways of hazardous constituent release and transport;

    b. population activity and land use patterns at and near exposure points; and

    c. magnitude, source and probability of exposure to specified hazardous constituents.

5. Identification of the contribution to the overall risk (exposure) for each exposure route posed by releases to soil should be determined including:

    a. dermal contact with soils;

    b. ingestion of soils (particularly important for ages under 6);

    c. inhalation of airborne particulates (with subsequent reingestion); and

    d. ingestion of contaminated biota.

Hazard Assessment

The purpose of hazard assessment is to determine the nature and extent of health and environmental effects associated with exposure to the hazardous constituents identified in the assessment of the extent of contamination.

This section can be divided into two subsections consisting of a toxicological review and a dose-response assessment. Toxicological and dose-response assessment information for hazardous constituents of concern can be found in the Health Effects Assessment (HEA) documents available through EPAs Office of Emergency and Remedial Respones (OERR) or in the Toxicological profiles available through EPAs Office of Waste Programs Enforcement.

Risk Characterization

The purpose of risk characterization is to integrate the findings of all the previously described sections in order to estimate facility specific risk to human health and the environment. Individual lifetime risks and total population risks can generally be calcuated for average and maximum levels of hazardous constituents in soil and other affected media (e.g., air, biota).

1. The risk characterization should address all types of potential or actual risks posed by the constituent release including:
    a. carcinogenic risks;
    b. non-carcinogenic risks; and
    c. environmental risks.
2. The weight of evidence associated with each step in the risk characterization process must be considered and include:
    a. estimated uncertainties;
    b. assumptions; and
    c. data gaps.
3. Risk estimations can be determined for
    a. carcinogens - by multiplying carcinogenic potency value by the current and projected chronic exposure levels;
    b. non-carcinogens - by comparing the projected exposure levels to acceptable levels; and

c. environmental risk

   1) by identifying the toxic effects of exposures to the chemicals of concern to wildlife, and
   2) by discussing the effects of exposure on indigenous species, on the food chain and on the habitat.

4. The overall risks from exposure to hazardous constituents may be determined by:

   a. estimating the exposures from individual hazardous constituents released;

   b. estimating the exposure from specific exposure routes;

   c. determining the additive/synergistic/antagonistic effects that may result from exposure to multiple constituents by various exposure routes; and

   d. reviewing the metabolic/reactive/adsorptive pathways of hazardous constituents.

SUMMARY

The above generic approach can be used to develop a comprehensive understanding of the risk posed by release of a hazardous constituent from a SWMU at a RCRA facility. The underlying components of the SWMU assessment/exposure assessment process are closely integrated and build upon each other. An organized, logical evaluation process ensures that all issues have been examined either qualitatively or quantitatively, and that risk characterization efforts are developed on a sound, documented data base. This generic approach can be used as a framework to identify the particular release (e.g. soil) and routes of exposure at any given RCRA facility, that presents adverse threats to public health and the environment.

SECTION 3

OVERVIEW OF CORRECTIVE MEASURES

GENERAL

Upon discovery of a release from a solid waste management unit at a RCRA facility, a complete site investigation should be performed to determine the nature and extent of the release. Once the release and its extent has been characterized, and determined to be a threat to human health or the environment, corrective measures must be implemented. This section discusses the various types of removal/containment (includes disposal) and treatment technologies which are applicable to remediation of releases to soils.

Table 3-1 lists the proven and imminent removal/treatment technologies discussed in this section, and also lists emerging technologies. Proven technologies are those technologies that have been used successfully at various sites to clean up hazardous wastes from soils. Imminent technologies are those that have been proven in the laboratory and successfully used in the field on pilot-scale studies. Emerging technologies are those technologies that, at the present time, are in the laboratory testing stage or possibly have been used in the field with either unknown or variable results.

Much of the information in subsequent discussions on the following proven and imminent technologies were excerpted from a report by JRB Associates entitled "Review of In-Place Treatment Techniques for Contaminated Surface Soils," September 1984; these technologies include chemical oxidation, chemical reduction, photolysis, biodegradation, sorption, attenuation, neutralization, and extraction (soil flushing).

Table 3-2 provides an overview of the hazardous constituents which are amenable to each proven removal/treatment technology, presented in this report, along with some general comments about the technology. Following this table are more detailed discussions of each proven and imminent removal/treatment technology. In addition to these technologies, natural treatment

TABLE 3-1. REMOVAL (CONTAINMENT)/TREATMENT TECHNOLOGIES

Proven Technologies	Imminent Technologies	Emerging Technologies
Excavation	Vaults	In Situ Vitrification
Offsite Disposal	Mobile Hazardous Waste Extraction	Chemical Degradation (dechloronation)
Onsite Capping	Fluidized-Bed Incineration	Ion Exchange
Onsite Landfilling	Mobile Advanced Electric Reactor	Polymerization
Soil Solidification	Attenuation	Reduction of Volatilization
In situ Biodegradation	Chemical Oxidation	Volatilization
Above-Grade Biodegradation	Chemical Reduction	
Photolysis	Extraction (Soil Flushing)[a]	
Neutralization	Multiple-Hearth Incineration	
Adsorption		
Rotary Kiln Incineration		
Mobile Rotary Kiln Incineration		

[a] Includes mobile EPA unit.

TABLE 3-2. SUMMARY OF PROVEN REMOVAL/TREATMENT TECHNOLOGIES

Removal/Treatment Technology		Amenable Hazardous Constituents	Comments
Removal (Containment)	Treatment		
Excavation		All constituent types	Factors affecting the feasibility of this technology includes: depth of contamination, and ground-water table, dust problems, stability of soils, accessibility, and volume of contaminated soil.
Cap Installation and Surface Sealing		Most constituent types*	Capping prevents direct contact with hazardous constituents and may minimize offsite migration via ground-water contamination. May not be effective in areas with a high ground water table. Capping does not comply with RCRA regulations for land disposal of hazardous constituents. Regular maintenance of the cap is required to maintain the integrity of the unit.
Offsite Disposal		All constituent types	Factors affecting the feasibility of this alternative include: availability of offsite disposal capacity, hazardous constituent toxicity, distance to disposal facility, transportation hazards, and costs.
Onsite Landfill		All types of soil contamination	Factors affecting the feasibility of this technology include: depth of ground water table, volume of hazardous constituents to be disposed, seismic conditions, constituent toxicity, persistance of hazardous constituents, and suitability of geology for landfill construction. Regular maintenance is required to maintain the integrity of the unit. Can be designed to comply with RCRA land disposal regulations.
	Solidification	Inorganics are more amenable than organics	Solidification alters the physical and/or chemical state of the hazardous constituents within the soil which renders them less leachable, less toxic, and more easily handled, transported and disposed. The primary solidification processes are cement-based and pozzolanic processes. Solidified materials generally have low durability and must, therefore, be protected from freeze/thaw and wet-dry cycles. Solidification greatly increases the volume of hazardous material.
	Biodegradation (In situ/Above-Grade)	Some organics**	Biodegradation is a highly effective and generally cost-effective biological treatment technology for hazardous constituents which are readily biodegradable. Shallow soils may be treated in situ whereas deep contamination may need to be excavated and treated above grade. The rate of decomposition of an organic constituent depends on its chemical composition and those factors which affect the soil environment such as pH, temperature, moisture content, aeration and oxygen supply, nutrients, and carbon/nitrogen ratio.

(continued)

TABLE 3-2 (continued)

Removal/Treatment Technology		Amenable Hazardous Constituents	Comments
Removal (Containment)	Treatment		
	Photolysis	Organic compounds with moderate to strong adsorption in the >290 nm wavelength range	Photodegradation results when ultraviolet energys break the carbon-halogen bond, thus dehalogenating the molecule. Photolysis is a major fate of many organic compounds. The photochemical characteristics of the hazardous constituents and climatic conditions affect the suitability of this process.
	Neutralization	Acidic or basic constituents	Neutralization can result in metal immobilization, decreased corrosivity, enhanced microbial activity, etc. Factors influencing the effectiveness of neutralization include: hazardous constituent characterization, soil conditions, depth of contamination, and geological/hydrological conditions.
	Adsorption	Heavy metals and organics	Agricultural products, sewage sludge, and activated carbon, among other organic materials, have been utilized to immobilize hazardous constituents in soils. The technology is more reliable over the short term. In the case of organics, sorption may immobilize constituents until they can be biodegraded.
	Rotary Kiln Incineration (Stationary/Mobile)	Organic constituents	Stationary rotary kilns have proven to be effective for incineration of a wide variety of solid hazardous wastes. Long residence times in the rotary kiln and high temperatures result in complete incineration of organic materials. High costs are associated with this technology. Three commercial units available are: Rollins Environmental Services, Deer Park, Texas; ENSCO, El Dorado, Arkansas; and SCA Services, Chicago, Illinois. Mobile rotary kilns have also been proven to be effective for incineration of solid wastes.

*Capping of highly soluble hazardous constituents is not recommended.

**Only those constituents amenable to biological attack.

mechanisms such as volatilization, photolysis and biodegradation may effectively remove hazardous constituents from soil. Variables affecting these mechanisms include soil and climate conditions, hazardous constituent characteristics, toxicity, leachability and depth.

Each of the proven technologies will be discussed under the following categories.

- General Description - discusses the technology and the various procedures and parameters that are involved.
- Hazardous Constituents Amenable to the Technology - describes the types of hazardous constituents that, when contained in the soil horizon, can or cannot be adequately treated with the technology.
- Performance - presents the effectiveness of a corrective measure in mitigating a human health or environmental risk in terms of its overall performance.
- Reliability - discusses the demonstrated performance and operation and maintenance requirements of corrective measures; including various parameters that may optimize or adversely affect the reliability of a measure.
- Implementability - presents the various parameters that affect the relative ease of initiating a corrective measure such as onsite and offsite conditions along with time to characterize the constructability of the corrective measure.
- Cost - reports the general costs for the proven technologies. However, it must be stressed that in most cases costs are highly variable due to various site-specific and constituent-specific characteristics. Therefore, reported costs should only be used for technology comparisons.

PROVEN TECHNOLOGIES

Excavation

General Description--

Excavation is an important technology for the treatment and disposal of contaminated soils. Excavation can normally be performed in a relatively quick, efficient, and cost-effective manner. However, if the contaminated soils are very deep or below the water table, excavation can become expensive, technically difficult and, therefore, may not be a viable corrective measure.

Excavation is also performed in conjunction with other technologies. Many corrective measures such as capping, onsite landfilling, offsite disposal, or many treatment technologies rely on the ability to excavate the contamination in order to be able to implement the corrective measure. However, if hazardous constituents cannot be excavated due to economic or technical issues, an in situ treatment method should be considered.

Excavation is widely used for removing surface and subsurface contaminated soils. This activity is normally conducted with the following types of equipment:

- backhoe,
- front-end loader,
- bulldozer,
- clamshell, and
- dragline.

Hazardous Constituents Amenable to the Technology--

Essentially all types of contaminated soils can be excavated with any readily available machinery (indicated above). However, an important consideration during excavation is the health and safety of workers. Fugitive dust emissions which are easily generated must be minimized throughout excavation processes by various methods of dust suppression.

Performance--

Excavation of contaminated soils is a very effective method of dealing with a soil release from a SWMU. Once the soils are excavated there are many options for cleanup that may be implemented. Therefore, the ability to excavate the soils is a benefit when attempting to develop and implement a corrective measure.

Reliability--

Excavating contaminated soils is a very reliable removal method as long as sampling is performed to ensure that all of the contaminated soils are removed. Removal of all contaminated soil eliminates the hazardous constituent source and its potential impact on human health and the environment.

Implementability--

Site conditions are the principal factors effecting the ability to excavate contaminated soil. For example a leak or spill that has only contaminated shallow soils may easily be removed. However, soils that are deep (i.e., under a landfill) or below the water table may require quite extensive excavation methods which greatly increase the time needed to implement a corrective measure. However, once soils are removed, beneficial results should be realized immediately and the threat to human health and the environment should be mitigated.

Cost--

Costs for excavation must also be considered in the final overall decision. Excavation costs can, however, vary greatly depending on the depth of contamination and proximity to the ground-water table. Table 3-3 indicates 1985 unit costs for various types of excavation equipment. Actual costs for excavation can be increased by 50 percent or more for health and safety reasons (SCS Engineers, 1981).

TABLE 3-3. UNIT COSTS - EXCAVATION OF UNCONTAMINATED SOIL

Equipment	1985 Unit Cost ($/cubic yard)
Backhoe	2.44 - 3.30
Dragline	1.66 - 3.50
Clamshell	3.23 - 4.83
Dozer	.31 - 4.52
Front-end Loader	.84 - 1.51
Gradall	3.11 - 3.80
Scraper	2.11 - 3.98
Power Shovel	1.25 - 3.28

Source: R.S Means, 1985.

Technical difficulties can also greatly increase the cost of excavation. If the contaminated soils are deep, below the water table or if sheeting/shoring is needed to support the excavation, costs can greatly be increased due to a loss of efficiency.

Offsite Disposal

General Description--

Offsite disposal is a removal/containment corrective measure, and can be implemented once the extent of soil contamination is determined. It requires additional remedial measures involving the excavation, loading and hauling of contaminated soils to an approved facility for final disposal.

Hazardous Constituents Amenable to This Technology--

Essentially all contaminated soils can be disposed of at a properly permitted facility. Most hazardous constituents, as a result of the 1984 HSWA amendments, require disposal at a double-lined facility. Some contamination such as foundry wastes, however, may be disposed of in a single-lined landfill.

Performance--

Offsite disposal is a very effective long-term disposal action for contaminated soil. If the extent of contamination is well-defined and sampling is performed during soil excavation then essentially all of the contamination (i.e., soil) should be effectively removed. This measure has a long useful life since, once removed, the contaminated soil will not cause any additional problems at the SWMU.

Reliability--

Offsite disposal is a very reliable corrective measure since the contaminated soils are removed from the facility and therefore, continued operation and maintenance activities are not required. However, based on the 1984 HSWA amendments, landfilling of untreated hazardous wastes are soon to be banned thereby, requiring that contaminated soils be treated prior to disposal.

Implementability--

The implementability of offsite disposal is subject to the limitations of excavation which have previously been discussed. Additionally, issues such as hauling distances, availabiity of landfill space, and quantities of soil must also be considered since they greatly influence the implementability and costs associated with the corrective measure. A considerable amount of time will be needed to complete the remedial action if the soils are difficult to excavate, are large in quantity, or if the permitted landfill is a long distance away. However, once the contaminated soils are removed, beneficial results should be realized immediately.

Accidental spillage during transportation must be considered as a safety issue. All soils must be shipped in accordance with various EPA and DOT regulations to minimize the possibility of problems during transportation.

Cost--

Factors which effect excavation costs also influence offsite disposal costs. Additionally, hauling distance and availability of landfill space effect overall disposal costs. Costs have recently (March 1985) been reported to GCA Corporation for disposal (i.e., tipping fee) by GSX Corporation of Pinewood, North Carolina as being approximately $100/yd^3. Transportation costs are generally high, very site-specific, and influenced by hauling distances and equipment availability.

Cap Installation and Surface Sealing

General Description--

Cap installation and surface sealing are corrective measures which can be performed to excavated contaminated soils or over existing in-place contamination. Capping consists of either impermeable capping which acts to prevent surface water infiltration and eliminates direct hazardous constituent contact, or permeable capping which differs from impermeable in that it allows surface water infiltration.

Impermeable capping can consist of a single synthetic or natural cover system which includes: a topsoil layer, atop a buffer/drainage layer, atop an impermeable layer, atop a bedding layer; or, a multimembrane system which includes a topsoil layer, atop a synthetic membrane, atop a bedding layer, atop a natural impermeable layer (i.e. clay).

Table 3-4 lists the types of materials used to cap contaminated soils.

TABLE 3-4. CAPPING/SURFACE SEALING MATERIALS

Synthetic Materials	Natural Materials
Asphalt	
Bitumen cements or concretes	Bentonite
Bituminous fabrics	Clay
Butyl rubber	Soil
Elasticized Polyolefin	
EPDM (ethylene-propylene-unsaturated dienoterpolymer)	
Hypalon	
Liquid emulsified asphalts or tars	
Neoprene rubber	
Polyolefin (Polyethylene and chlorinated polyethylene)	
Portland cements or concretes	
PVC (Polyvinyl chloride)	
Sulfur (thermoplastic coating)	
Teflon - coated fiberglass (TFE)	

Source: EPA, 1983b.

Hazardous Constituents Amenable to the Technology--

Most types of contaminated soil can be disposed in an impermeable capped structure. The use of bottom liners, however, is required to comply with various RCRA regulations.

Hazardous constituent/membrane compatability is an issue of concern when considering impermeable capping. Hazardous constituents contacting an impermeable membrane can lead to premature membrane degradation and failure. Problems can arise when an impermeable cap is placed above soils contaminated with highly soluble constituents without the added protection of a bottom liner and leachate collection/detection system. If the cap is breeched, constituents with high aqueous solubilities and low octanol-to-water partition coefficients will tend to mobilize from the soils and migrate into the ground water. Therefore, the impermeable capping of soils with soluble hazardous constituents is not advisable unless there is a bottom liner or unless site conditions dictate that migration is unlikely. This restriction is also applicable to permeable capping of contaminated soil whereby permeable capping may be acceptable if the hazardous constituents are not mobilized by surface water infiltration.

Performance--

Impermeable capping is, in general, relatively effective as a removal/containment measure, in that it can prevent surface water infiltration and can preclude human contact with contaminated soil. This corrective measure is best suited in areas where there is a safe distance between the bottom of the contaminated soils and the mean high ground water table. This environmental feature will act to protect ground water in the event of a breech in the cap with subsequent hazardous constituent generation. Impermeable capping is enhanced when site soils are of the type which minimize hazardous constituent migration. This situation is particularly advantageous if a bottom liner is not present. Capping suffers the disadvantage that cap failure may result in surface water infiltration and subsequent constituent migration.

A permeable cap like the impermeable cap is a relatively effective means of isolating contaminated soil as long as its limitations are recognized. A permeable cap is expected to have a long useful life as long as the cover material is properly maintained and erosion is eliminated. However, if erosion occurs then direct contact with the contaminated soils would be possible.

Reliability--

Impermeable or permeable caps must be maintained to function properly. Operation and maintenance activities such as inspections to ensure continued cap integrity, mowing and revegetation and erosion control measures are crucial to obtaining the maximum useful life for this type of structure. Ground water monitoring is also required to detect leachate generation or hazardous constituent migration. This corrective measure is often used in conjunction with other remedial measures for site clean up. For example, pumping or french drains are used to aid in ground water cleanup. The use of impermeable and permeable caps to isolate soils must be carefully investigated prior to their installation at a SWMU. It must be determined that the cap will be able to perform as intended and that the soil contamination will not migrate or impact human health and the environment.

Implementability--

The principal consideration in regards to implementing and installating a cap are site conditions, and time. While permeable and impermeable caps can usually be installed in a relatively short (i.e., several months) time period, equipment and material constraints can increase the period of time required to implement these measures.

Cost--

Some general costs for permeable and impermeable materials are presented in Table 3-5. These costs do not include any costs for excavation or any other site activities.

Onsite Landfill

An onsite landfill may be used to dispose of contaminated soil from a release at a SWMU. However, if the SWMU is a landfill and the leak/release can be repaired, then the newly contaminated soil can be returned to the

TABLE 3-5. CAPPING/SURFACE SEALING UNIT COSTS

Material	Unit Cost (June 1985)*
Topsoil (sandy loam), hauling, spreading, and grading (within 20 miles)	$16.85/yd^3$
Clay-rich soil, hauling, spreading, and compaction	$11.30/yd^3$
Sand, hauling, spreading, and compaction	$20.34/yd^3$
Portland cement concrete (4 to 6 in. layer), mixed, spread, compacted onsite	$10.17 - $16.95/yd^2$
Bituminous concrete (asphalt pavement) (4 to 6 in. layer), including base layer	$5.08 - $8.19/yd^2$
Lime or Portland cement, mixed into 5 in. of cover soil	$2.43 - $3.39/yd^2$
Bentonitic clay (2 in. layer) spread and compacted	$2.14/yd^2$
Sprayed asphalt (1/4 in. layer), with cover soil, installed	$2.26 - $3.84/yd^2$
PVC membrane (20 mil), installed	$1.97 - $3.05/yd^2$
Chlorinated PE membrane (20 to 30 mil), installed	$3.67 - $4.86/yd^2$
Elasticized polyolefin membrane, installed	$3.50 - $4.69/yd^2$
Hypalon membrane (30 mil), installed	$8.36/yd^2$
Neoprene membrane, installed	$8.19/yd^2$
Ethylene propylene rubber (EPDM) membrane, installed	$4.07 - $5.31/yd^2$
Butyl rubber membrane, installed	$4.07 - $5.76/yd^2$
Teflon-coated fiberglass (TFE) membrane (10 mil), installed	$26.00/yd^2$
Fly ash and/or sludge spreading, grading, and rolling	$1.69 - $2.82/yd^2$

Source: Radian Corporation, 1983.

*Costs updated to June 1985 dollars by GCA Corporation/Technology Division.

repaired landfill. If the landfill has installation defects or quality control was poor during installation, then conceivably a completely new landfill may need to be constructed to adequately protect human health and the environment.

General Description--

Landfilling of contaminated soils has been used for many years as a means of storage and permanent disposal of all types of contaminated soils. Landfilling generally consists of placing soils into either a lined or unlined excavated area and then placing a cap over these soils. If the ground water table is very shallow, landfills can also be constructed above grade in mounds. The general types of landfills include:

- "state-of-the-art" RCRA-designed landfills,
- single-lined landfills, and
- unlined landfills.

A "state-of-the-art" RCRA-designed landfill generally consists of impermeable liners, and leachate collection and leak-detection systems for both its cap and bottom liner systems. Of the three types of landfills identified above, a RCRA landfill offers the greatest amount of protection to the environment since it essentially eliminates surface water infiltration and hazardous constituent migration into the ground water. A 30-year post closure ground water monitoring period is, however, required.

A single-lined landfill consists of one liner, a leachate collection system comprised of a drainage layer and perforated pipes, and an impermeable cap. Such landfills also require post-closure ground water monitoring for a 30-year period.

An unlined landfill consists of an unlined trench with an impermeable cap and no leachate collection system. While this type of landfill can be effective under certain conditions, there is always the possibility of leachate being generated and subsequently migrating to the ground water.

Factors that must be considered when assessing the suitability of landfilling include:

- The physical state and solubility of wastes within the contaminated soils to be landfilled. The materials must be amenable to being compacted and securely placed to eliminate differential settling and avoid landfill failure.

- Present land use and the depth to ground water.

- Geologic conditions such as soil permeability, location of bedrock, impermeable strata, and seismic zones.

- Location within a 100-year floodplain.

Hazardous Constituents Amenable to the Technology--

Generally most types of contaminated soil can be landfilled. However, the compatibility of any generated hazardous constituent and the liner must be determined prior to installation to ensure that hazardous constituents generated will not adversely affect the integrity of the liner. Adverse effects on the liner can lead to premature breeching and decrease in useful life.

Performance--

RCRA landfills are expected to be very effective in containing contaminated soils since they have many safeguards against hazardous constituent discharge. This type of double-lined landfill encapsulates the soils thereby minimizing hazardous constituent generation and preventing constituent release into the environment (assuming QA/QC procedures during construction and operation are strictly adhered to).

A single-lined landfill will be somewhat less effective in containing contaminated soils since it only has one liner. This type of landfill is also not expected to have as long a useful life as a double-lined RCRA landfill.

An unlined landfill is even less effective at providing protection to human health and the environment since cap failure can occur thus allowing hazardous constituent migration into ground water. Unlined landfills must be carefully sited.

Reliability--

Properly designed and installed landfills are generally quite reliable. There are, however, many operational and maintenance activities that are necessary to ensure proper functioning of the landfill. For example, maintenance and repair to the cap during establishment of the vegetative cover is a critical and extensive activity. Landfills having leachate collection and leak detection systems also require continuous monitoring. Other activities such as cleaning collection system drain pipes may occasionally be necessary. All of these activities greatly effect the reliability of landfilling contaminated soils.

Implementability--

Some of the site conditions that may affect the implementability of an onsite landfill are:

- bedrock outcropping;
- shallow ground water table; and
- physical space for the landfill.

If the bedrock is shallow or if outcroppings are erratic then siting a landfill may be impossible due to the lack of depth. Very shallow ground water makes installation difficult since dewatering may be required to excavate and place the landfill layers. In these cases an above-grade or mounded landfill may be applicable.

Landfills can generally be constructed within a few months; however this is greatly dependent on the amount of soil to be landfilled and the overall site conditions. Once the soils are placed in the landfill, immediate beneficial results should be realized, since the soils will no longer contribute to continued contamination.

Cost--

A double-lined landfill can be constructed for approximately \$60 to \$80/yd^3 (GCA, 1985b). A single-lined landfill can be constructed for approximately 15 percent less than a double-lined facility and therefore, ranges from \$50 to \$70/yd^3. An unlined landfill consisting of an impermeable cap can be expected to cost approximately \$30/yd^3.

Solidification

General Description--

Soil solidification or stabilization is a process that alters the physical and/or chemical state of the hazardous constituents within the soil rendering them less leachable, less toxic, and more easily handled, transported, and disposed. With current solidification technologies, inorganic constituents are essentially the only types of constituents that are amenable to solidification. Generally contaminated soils containing greater than 10 to 20 percent organics cannot be solidifed (U.S. EPA, 1980). The main types of solidification for soils consist of:

- cement-based processes; and
- pozzolanic processes.

Cement-based processes generally consist of a soil/slurry mixed with a Portland cement. This mixture then hardens in a matter of hours or days forming a rock-like mass incorporating the hazardous constituents into the crystalline structure.

Most types of hazardous constituents contained in soils and slurried in water can be solidified since suspended solids are readily incorporated into the structure. There are also chemical reactions that occur when the hazardous constituents and cement are combined that can alter the state of the hazardous constituents. The final product from the process is generally stable and inert, however, leaching can still occur. To prevent this, surface coating for the solidified mixtures consisting of asphalt, asphalt emulsion and vinyl have been investigated quite extensively. However, surface coatings are currently not used with great success due to poor adhesion.

Pozzolanic solidification processes involve the reaction of lime with fine-grained siliceous (pozzolanic) materials plus water to produce a concrete-like mass. Pozzolanic materials generally consist of fly ash, ground blast-furnace slag and cement-kiln dust. These products are byproducts of commercial products with very little economic value. This activity can be advantageous since two constituent products are combined to form a solid mass that can be easier to dispose.

As with the cement-based process, the pozzolanic process does not completely eliminate leaching in all cases. Therefore, disposal of these solidified hazardous constituents necessitates the use of a specially designed landfill that will contain and remove leachate if produced.

Hazardous Constituents Amenable to the Technology--

Inorganics are the principal types of hazardous constituents that are amenable to solidification. During the solidification process chemical conversions can occur as the contaminated soil and binding agent are mixed. For example, toxic metals can be easily precipitated as insoluable hydroxides or carbonates by the high pH of the cement. Other materials such as soluble salts of zinc, copper, lead, manganese, and tin tend to cause variations in setting times which greatly reduces the physical strength of the mixture. Also, the presence of fine organic particles such as those passing through a No. 200 mesh sieve are undesirable and tend to weaken the bond between cement particles (EPA, 1980). Also, soils that contain high levels of sulfates greatly increases the swelling of concrete which can cause spalling.

Performance--

Solidification is normally used on sludges and aqueous wastes. The process of solidification is generally quite effective, however, since leaching is not completely eliminated, disposal in a secure landfill is necessary (EPA, 1980). Over the short term this corrective measure may perform quite adequately, however, various processes (i.e., freeze-thaw, contact with water) can reduce the long-term effectiveness.

Reliability--

This process is reported to be quite reliable as long as the hazardous constituent/solidifying agent compatibility are taken into account; types of hazardous constituents that can be solidified have been discussed previously. After solidification, if the material is to be landfilled, testing should be conducted to ensure that no harmful reactions will occur if leachate is generated.

Implementability--

The solidification process is, in general, easily implemented. In both the cement-based and pozzolanic processes, materials are readily available and extensive hazardous constituent/soil dewatering is not necessary. Special equipment is generally unnecessary since lime is a common additive and cement-mixing is a common technology.

Cost--

The costs for solidification with Portland cement is dependent on the physical state of the hazardous constituents and amount of soil to be solidified. Portland cement is estimated to cost from $65 to $90/ton (Radian Corporation, 1983).

The costs for solidification using pozzolanic processes are estimated to be from $0.04 to $0.15/gallon for industrial sludges (EPA, 1982b).

In Situ Biodegradation

General Description--

Biodegradation is a biological treatment process which constitutes the molecular breakdown of organic substances by living organisms. It is a significant mechanism for degrading organic compounds in soil environments which typically contain diverse microbial populations including bacteria, actinomycetes, and fungi. Important parameters in the soil environment which affect biodegradation include pH, soil moisture content, soil oxygen content, nutrient concentrations, and temperature. In situ biodegradation of contaminated soils can be enhanced by modifying soil parameters or by supplementing existing microbial populations with other natural microbes, adapted microbial cultures, or bioengineered microbial strains. Soil parameters, as summarized in Table 3-6 and subsequently discussed, are modified to enhance microbial growth and substrate utilization. This includes: (1) increasing soil temperatures to between 50° and 60°C; (2) increasing soil water potential to greater than -15 bars; (3) adjusting soil pH to between 5 and 9; (4) adjusting the oxidation-reduction (redox) potential of the soil; and (5) addition of nutrients. While the status of the in situ biodegradation technology is at various stages of development,

TABLE 3-6. MODIFICATION OF SOIL PARAMETERS

Soil Parameter	Control Method	Comments
Temperature	• Vegetation • Mulching • Irrigation • Drainage • Compaction • Tillage • Humic substance addition	Vegetation and mulching regulate incoming and outgoing radiation, other methods alter the thermal conductivity of soils themselves
Moisture content	• Irrigation	Most suitable irrigation treatment for contaminated soils appears to be sprinkler (overhead) irrigation due to adjustable application rates, uniform water distribution, and control over erosion
	• Drainage	Includes surface drains, i.e., open ditches and lateral drains, and subsurface drains, i.e., open ditches, buried tube drains, and well points
	• Additives	Includes commercially available water storing agents, water repelling agents, surface active agents and evaporation retardants
pH	• Liming	Calcium or calcium and magnesium-containing compounds used to raise the pH
	• Sulfur or acid-producing substances	Substances used to lower the pH, little experience in field applications

(continued)

TABLE 3-6 (continued)

Soil Parameter	Control Method	Comments
Oxygen content	• Aerobic conditions	
	- Tillage	Surface soils (<2 ft deep)
	- Well-point injection	Soils >2 ft deep (saturated)
	- Drainage	
Nutrients	• Commercial fertilizers	Usually nitrogen or phosphorus additives

depending upon the technique used and the hazardous constituents being treated, the control methods corresponding to each soil parameter presented in Table 3-6 have been field tested.

Soil temperature is one of the more important factors in controlling microbiological activity, the rate of organic matter decomposition, and the rate of volatilization of compounds from soil. It can be modified by regulating incoming and outgoing radiation through vegetation and mulching, or by changing the thermal properties of the soil with irrigation/drainage, compaction/tillage and the addition of humic substances (JRB Associates, 1982).

The degradation of hazardous organic compounds can be accelerated by optimizing soil moisture. Limited experimentation indicates that degradation rates are highest at a soil water potential between 0 and -.9869 atm. Typical methods of moisture enhancement include irrigation and synthetic soil additives. If the soil is too wet, surface erosion due to runoff will mobilize contaminated soils and render them unavailable to biodegradation. Therefore, soil drainage is also an important method of moisture control. Care must be taken however not to promote hazardous constituent migration in the process (JRB Associates, 1982).

Depending upon the nature of the hazardous constituents contaminating the soil, it may be advantageous to optimize the soil pH for a particular segment of the microbial population. Some fungi have a competitive advantage at slightly acidic pH, while actinomycetes flourish at slightly alkaline pH. Near neutral pH values are probably most conductive to microbial functioning in general. Contaminated soil can be treated with crushed limestone or lime products to raise the pH to the desired range, or with acid-producing materials or sulfur to lower the pH (JRB Associates, 1982).

The oxygen content of the soil can also determine the mechanism of biodegradation through anaerobic and aerobic processes; only aerobic processes will be discussed in the document. Aerobic processes are more energy-efficient and microbial decomposition processes are more rapid under these conditions. The majority of organisms in soils decompose under aerobic conditions. Common methods of aeration are tilling or draining the soil. If deep soils require aeration, a backhoe (or other form of construction equipment) or a well point system for diffusers can be used.

Microbial degradation may also be limited by nutrient availability, particularly if available carbon (C) is in large excess relative to the nitrogen (N) and/or phosphorus (P) required by the microorganisms that degrade it. If the ratio of organic C:N:P is greater than about 300:15:1 and available (extractable) inorganic forms of N and P do not narrow the ratio to within these limits, supplemental nitrogen and/or phosphorus should be added (Alexander, 1977; Kowalenko, 1978).

Adding fertilizer to hasten the decomposition of crop residues is used in agriculture (Alexander, 1977), and has been used in the treatment of hazardous waste (oil spill) contaminated soils (Thibault and Elliott, 1980). For detailed discussions on the soil parameters previously presented that can be modified to promote biodegradation refer to JRB Associates (1982).

Table 3-7 lists some of the organic compounds amenable to microbial degradation. Table 3-8 lists microbial strains which have been effective at degrading pesticides.

Performance--

Enhanced biodegradation by soil modification has been widely and successfully performed in the agricultural industry. The use of specially adapted microorganisms has been demonstrated in the laboratory and has been used successfully in several full-scale soil decontamination operations (i.e., chemical spills).

The level of treatment for in situ biodegradation can be variable and depends on the soil conditions and the type of contamination. High percent removals of soil contaminants has been demonstrated after adequate pH adjustment, nutrient addition and application of adapted microorganisms.

The optimization of soil conditions for enhanced biodegradation, however, may result in the release and subsequent transport of hazardous constituents via the following mechanisms: leaching, erosion, dissolution, or precipitation.

Reliability--

The reliability of in situ biodegradation enhancement technologies for modifying soil parameters is moderate because they require considerable maintenance or reapplication. The use of adapted microbial populations is

TABLE 3-7. COMPOUNDS OR CLASSES OF COMPOUNDS THAT HAVE BEEN (OR COULD BE) DEGRADED BY COMMERCIALLY AVAILABLE MICROBIAL AUGMENTATION PRODUCTIONS

Alcohols

- n-Butyl alcohol
- Dimethylaminoethanol

Alkyl Halides

- Ethylene dichloride (1,2-Dichloroethane)
- Methylene chloride (Dichloromethane)
- Propylene dichloride (1,2-Dichloropropane)

Amines

- Dimethylaniline
- Trimethylamine

Aromatic Hydrocarbons

- Divinyl Benzene
- Polynuclear Aromatic Hydrocarbons (PNAs)
- Styrene (Vinyl Benzene)

Chlorinated Aromatics

- Polychlorinated biphenyls (PCBs)

Esters

- Methacrylates

Ketones

- Acetone

Nitriles

- Acrylonitrile

Phenols

- Phenol
- Metachlorophenol
- Orthochlorophenol
- Pentachlorophenol
- Resorcinol (1,3-Benzenediol)
- t-Butylcatechol

Crude and refined oils

Emulsifiers

Detergents

Source: EPA, 1984b.

TABLE 3-8. MICRO-ORGANISMS KNOWN TO METABOLIZE ORGANOCHLORINE PESTICIDES

Microorganism	Pesticides
Bacteria	
Arthrobacter	Endrin, DDT
Bacillus	Endrin, DDT
Clostridium	Lindane
Escherichia	DDT
Hydrogenomonas	DDT
Klebsiella	DDT
Micrococcus	Endrin, Aldrin, DDT
Proteus	DDT
Pseudomonas spp.	Endrin, Aldrin, DDT
Pseudomonas spp.	Heptachlor
Pseudomonas	Dieldrin
Unidentified	Dieldrin, Aldrin, Endrin, DDT
Unidentified	Lindane, Aldrin
Actinomycetes	
Nocardia	DDT, PCNB
Streptomyces	PCNB
Fungi	
Aspergillus	PCNB
Fusarium	DDT
Mucor	Dieldrin
Trichoderma	Dieldrin
Yeast	
Saccharomyces	DDT
Algae	
Chlamydomonas	Lindane
Chlorella and Dunaliella	Aldrin

Source: DeRenzo, 1980.

also moderately reliable due to their dependence on soil parameters. Biodegradation generally results in less complex, though not necessarily less toxic, compounds. For example, the degradation products of some halogenated organics such as DOT, DDE, and DDD have been found to be more toxic and persistant than their parent compounds.

Implementability--

The implementability of this treatment technology is variable because it depends rather heavily on soil properties and site conditions including moisture content, trafficability, and depth of contamination. Usually standard agricultural equipment and techniques, and commercially available materials are required.

Cost--

Costs for in situ biological treatment are highly variable and site specific, and therefore are not readily approximated (Ronyak, 1985).

Above-Grade Biodegradation

General Description--

The previous discussion on biological treatment focused on in situ methods for enhancing biodegradation. Above-grade biodegradation, a biological treatment technology, differs from in situ biodegradation in that it can be implemented in instances where in situ treatment is not possible; for example, when the contaminated soil is at considerable depth. Other conditions such as a high water table, potential for migration of hazardous constituents, the need to recirculate bacterial and nutrient solutions, and numerous other factors may require that the contaminated soils be excavated and located above grade for subsequent biodegradation.

In above-grade biodegradation treatment, the preliminary activity is the excavation of contaminated soils. The excavated soils are then placed in a lined impoundment to facilitate the recycling of nutrient and bacterial solutions, and to collect the generated leachate. Alternatively, the excavated soil can be placed directly on natural soils for subsequent landfarming activities.

Performance--

The reliability of above-grade biodegradation treatment varies widely depending upon the nature of the contaminated soils to be treated. For example, soils contaminated with petroleum waste products may be readily biodegradable whereas soils contaminated with PCBs may not be suitable for treatment. The ability to effectively treat a contaminated soil can be ascertained by laboratory and pilot field tests.

Reliability--

Provided that biodegradation of a specific hazardous constituent has been proven to be effective, the process can be highly reliable. After treatment, sampling can be conducted to determine the effectiveness of the process. Higher levels of biodegradation are generally obtained when longer periods of biotreatment are used.

Implementability--

Above-grade biodegradation is generally readily implementable. Sufficient land must be available to spread out the contaminated soils for treatment. Construction of aeration tanks, impoundments, and irrigation systems are the major construction-related activities.

Cost--

As previously stated for in situ biodegradation, costs can be highly variable and are site specific (Ronyak, 1985).

Photolysis (Photooxidation)

General Description--

Photolysis or photooxidation is the process by which ultraviolet photons break the carbon-halogen bond (usually C-CL), resulting in a dehalogenated molecule. Such loss of halogens is considered favorable because lower-order halogenated organics usually have less toxic properties and are more biodegradable. Photodegradation is enhanced by the presence of a hydrogen donor which replaces the chlorine on the molecule. Hydrogen donors are applied and depending on the depth of contamination, the soil is tilled to expose hazardous constituents to the light.

Activated carbon adsorption of organics followed by chemical addition and photolysis has been reported by React Environmental Crisis Engineers, St. Louis, Missouri (1983). The method involves the addition of activated carbon to the soils, removal of the most highly contaminated materials, and mixing the remaining soil with sodium bicarbonate to increase soil pH. The soil is then allowed to react photochemically resulting in the photolysis of the parent material. The level of treatment is expected to be fairly high. An increase in soil pH is the major secondary impact of the treatment method.

Hazardous Constituents Amenable to Treatment--

Photodegradable organic constituents are amenable to this form of treatment. Generally, this includes compounds with moderate to strong absorption in the 290 nm wavelength range. Table 3-9 lists the of compounds which are amenable to photodegradation.

Performance--

The level of treatment achievable is potentially quite high, based on limited experimental data. Effectiveness also depends on the amount of tillage possible at the site and the depth of contamination. However, the potential for the production of hazardous compounds from photodegradation needs to be further researched. Production of hazardous compounds from the photodegradation of pesticides has been documented, e.g., dieldrin formation from aldrin, paraoxon formation from parathion, phosgene formation from chloropicrin (Crosby, 1971), and the formation of PCBs from the photoreaction of DDT (Woodrow et al., 1983). The potential for such occurrences is expected to be high and further research is needed to identify potential toxic product formation to ensure the safe application of this treatment methodology. Another concern is the potential induction of volatilization of organic constituents from the soil without subsequent photodegradation.

Reliability--

Unless the hazardous constituents in the contaminated soil and their photodegradation products are known, this is not a reliable method, since toxic by-products may be formed.

TABLE 3-9. ATMOSPHERIC REACTION RATES AND RESIDENCE TIMES OF SELECTED ORGANIC CHEMICALS

Compound	$k_{OH} \times 10^{12}$ (cm^3 molecule^{-1} sec^{-1})	Direct Photolysis Probability	Physical Removal Probability	Residence Time (Days)	Anticipated Photoproducts
Acetaldehyde[c]	16	Probable	Unlikely	0.03-0.7[c]	H_2CO, CO_2
Acrolein	44[a]	Probable	Unlikely	0.2	OCH-CHO, H_2CO, HCOOH, CO_2
Acrylonitrile	2	-	Unlikely	5.6	H_2CO, HC(O)CN, HCOOH, CN^0
Allyl chloride	28[a]	Possible	Unlikely	0.3	HCOOH, H_2CO, $CICH_2CHO$, chlorinated hydroxy carbonyls, $CICH_2COOH$
Benzyl chloride	3[a]	Possible	Unlikely	3.9	OCHO, Cl; ring cleavage products chloromethyl-phenols
Bio(Chloromethyl) Ether	4[a]	Possible	Probable	0.02-2.9[d]	$HCl+H_2CO$, CIHCO, chloromethylformate
Carbon Tetrachloride	0.001	-	Unlikely	11,000	Cl_2CO, CL^0
Chlorobenzene	0.4[a]	Possible	Unlikely	28	Chlorophenols, ring cleavage products
Chloroform	0.1	-	Unlikely	120	Cl_2CO, Cl^-
Chloromethyl methyl ether	3[a]	Possible	Probable	0.004-3.9[d]	Chloromethyl and methyl formate, CIHCO
Chloroprene	46[a]	Probable	Unlikely	0.2	H_2CO, H_2C=CCICHO, OHCCHO, CICOCHO, $H_2CCHCCIO$, chlorohydroxy acids, aldehydes
o,m,p-cresol[e]	55	-	Unlikely	0.2	hydroxynitrotoluenes, ring cleavage products
Dichlorobenzene[e]	0.3~~[a]~~	Possible	Unlikely	39	Chlorinated phenols, ring cleavage products
Dimethyl Nitrosamine	39[a]	Probable	-	≤0.3	aldehydes, NO
Dioxane	3[a]	-	Unlikely	3.9	$OHCOCH_2CH_2OCHO$, OHCOCHO oxygenated formates

(continued)

TABLE 3-9 (continued)

Compound	$k_{OH} \times 10^{12}$ (cm^3 molecule^{-1} sec^{-1})	Direct Photolysis Probability	Physical Removal Probability	Residence Time (Days)	Anticipated Photoproducts
Dioxin	-	Probable	-	-	-
Epichlorohydrin	2^a	Possible	Unlikely	5.8	H_2CO, OHCOCHO, $ClCH_2O(O)OHCO$
Ethylene Dibromide	0.25	Possible	Unlikely	45	Bi, $BrCH_2CH_2CHO$, H_2CO, Br HCO
Ethylene Dichloride	0.22	Possible	Unlikely	53	ClHCHO, $H_2CClCOCl$, H_2CO, $H_2CClCHO$
Ethylene Oxide	2^a	-	Unlikely	5.8	OHCOCHO
Formaldehyde[c]	10	Probable	Unlikely	$0.1-1.2^c$	CO, CO_2
Hexachlorocyclo-pentadiene	59^a	Probable	-	0.2	Cl_2CO, diacyclchlorides, ketones, Cl
Maleic Anhydride	60^a	Possible	Possible	0.1	CO_2, CO; acids, aldehydes, and esters which should photolyze
Methyl Chloroform	0.012	Possible	Unlikely	970	H_2CO, Cl_2CO, Cl·
Methylene Chloride	0.14	Possible	Unlikely	83	Cl_2CO, CO, ClHCO, Cl·
Methyl Iodide	0.004^a	Possible	Unlikely	2,900	H_2CO, I^0, ICHO, CO
Nitrobenzene	0.06^a	Possible	Unlikely	190	Nitrophenols, ring cleavage products
2-Nitropropane	55^a	Possible	Unlikely	0.2	H_2CO, CH_{3CHO}
N-Nitrosodiethylamine	26^a	Probable	-	≤ 0.4	Aldehydes, nitroamines
Nitrosoethylurea	13^a	Possible	-	≤ 0.9	Aldehydes, Nitroamines
Nitrosomethylurea	20^a	Possible	-	< 0.6	Aldehydes, nitroamines
Nitrosomorpholine	28^a	Possible	-	≤ 0.4	Aldehydes, ethers

(continued)

TABLE 3-9 (continued)

Compound	$k_{OH} \times 10^{12}$ (cm^3 molecule^{-1} sec^{-1})	Direct Photolysis Probability	Physical Removal Probability	Residence Time (Days)	Anticipated Photoproducts
Perchloroethylene	0.17	Possible	Unlikely	67	Cl_2CO, $Cl_2C(OH)COCl$, Cl^0
Phenol	17[a]	-	Possible	0.6	Diphydroxybenzenes, nitrophenols, ring cleavage products
Phosgene[f]	~0	-	Possible	-	CO_2, Cl^0, HCl
Polychlorinated Biphenyls	<1[a]	Possible	Unlikely	>11	Hydroxy PCBs, ring cleavage products
POM (Benzo(a)-pyrene)	-	Possible	Probable	8	B(a)P-1,6-quinone
Propylene Oxide	1.3	-	Unlikely	8.9	$CH_3C(O)OCHO$, $CH_3C(O)CHO$, H_2CO, $HC(O)OCHO$
Toluene	6	-	Unlikely	1.9	Benzaldehyde, cresols, ring cleavage products, nitro compounds
Trichloroethylene	2.2	Possible	Unlikely	5.2	Cl_2CO, $ClHCO$, CO, Cl·
Vinylidene Chloride	4[a]	Possible	Unlikely	2.9	H_2CO, Cl_2CO, HCOOH
o-,m-,p-xylene	16	-	Unlikely	~0.7	Substituted benzaldehydes, hydroxy xylenes, ring clevage products, nitro compounds

---

[a] Rate constant by method of Hendry and Kenley (1979).

[b] Material is not expected to exist in vapor phase at normal temperatures. Residence time calculation assumes the chemical is substantially absorbed by aerosal particles and that the aerosol particles have a residence time of approximately 7 days.

[c] The shorter residence time includes a photolysis rate as given in Graedel (1978).

[d] Decomposition in moist air is expected. The shorter residence time includes the cited decomposition rate.

[e] Values given are averages for the various isomers.

[f] Reaction with O('D) is possible; $k=3.6\times10^{-10}$ cm^3 molecule^{-1} sec^{-1}, and $[O('D)]=0.2$ molecules cm^{-3} implies a tropospheric lifetime of 440 years. In addition, slow hydrolysis is expected.

Source: EPA, 1984b.

Implementability--

Soil tilling may be easy or difficult depending on the trafficability of the site and the depth of contamination. Runon and runoff controls may be necessary to manage the drainage and erosion.

Cost--

Costs for this technology can be quite variable and are highly site dependent. If contamination is at the surface, then only tilling may be needed. If soils are somewhat deeper, then excavation followed by spreading at the surface will be necessay, thereby increasing costs.

Neutralization

General Description--

Neutralization is the addition of chemicals to contaminated soil to increase pH values to pH 7 or above. Control of soil pH can result in metal immobilization, decreased corrosivity, and enhanced microbial activity. The most common method of soil neutralization is liming, which involves the addition of any calcium or calcium and magnesium-containing compound to soil. The use of acidic chemicals to lower soil pH is not commonly employed at this time. Lime correctly refers to only calcium oxide, but is commonly used to refer to calcium hydroxide, calcium carbonate, calcium-magnesium carbonate, and calcium silicate slags. A summary of commonly used liming materials is presented in Table 3-10.

The choice of a liming material depends upon several factors. Calcitic and dolomitic limestones are the most commonly used materials. To be rapidly effective, these materials must be ground because the velocity of reaction is dependent on the surface in contact with the soil. The finer the materials are ground, the more rapidly they react with the soil. However, a more finely ground limestone product usually contains a mixture of fine and coarse particles in order to effect a pH change rapidly and still be relatively long-lasting as well as reasonably priced. Many states require that 75 to 100 percent of the limestone pass an 8- to 10-mesh sieve and that 20 to 80 percent pass anywhere from an 8- to 100-mesh sieve. Calcium oxide and calcium hydroxide are manufactured as powders and react quickly.

TABLE 3-10. LIMING MATERIALS

Liming Material	Description	Calcium Carbonate Equivalent[a]	Comments
Limestone, calcitic	$CaCO_3$, 100 percent purity	100	Neutralization value usually between 90-98 percent because of impurities; pulverized to desired fineness
Limestone, dolomitic	65 percent $CaCO_3$ + 20 percent $MgCO_3$, 87 percent purity[b]	89	Pure dolomite (50 percent $MgCO_3$ and 50 percent $CaCO_3$) has neutralizing value of 109 percent; pulverized to desired fineness
Limestone, unslaked lime, burned lime, quick lime	CaO, 85 percent purity	151	Manufactured by roasting calcitic limestone; purity depends on purity of raw materials; white powder, difficult to handle--caustic; quick acting; must be mixed with soil or will harden and cake
Hydrated lime, slaked lime, builder's lime	$Ca(OH)_2$, 85 percent purity	85	Prepared by hydrating CaO; white powder, caustic, difficult to handle; quick acting
Marl	$CaCO_3$, 50 percent purity	50	Soft, unconsolidated deposits of $CaCO_3$, mixed with earth, and usually quite moist
Blast furnace slag	$CaSi_2O_3$	75-90	Byproduct in manufacture of pig iron; usually contains magnesium
Waste lime products	Extremely variable in composition	?	-

[a] Calcium carbonate equivalent (CCE): neutralizing value compared to pure calcium carbonate, which has a neutralizing value defined as 100.

State laws specify a calcium carbonate equivalent averaging 85 percent.

Source: EPA, 1984b.

The amount of lime required for soil pH adjustment is dependent on several soil factors, including soil texture, type of clay, organic matter content, exchangeable aluminum and buffering capacity (Follett et al., 1981). Differences among soils in their buffering capacity reflect differences in the soil cation exchange capacities and will directly affect the amount of lime required to adjust soil pH. The amount of lime required is also a function of the depth of incorporation at the site, i.e., volume of soil to be treated. The amount of lime required to effect a pH change in a particular site/soil/waste system is determined in laboratory short-term treatability studies or soil-buffer tests (McLean, 1982). Lime requirements may also be affected by acid precipitation and acid-forming fertilizers.

Hazardous Constituents Amenable to Treatment--

Soil contaminated with acidic or basic constituents.

Performance--

Liming is a common agricultural technique where the achievable level of treatment is high, though care must be taken to ensure that hazardous constituents are not mobilized from the change in soil pH.

Reliability--

Reliming will probably be necessary to maintain an adequate level of treatment.

Implementability--

The implementability is quite variable, depending on the trafficability of the site and the depth of soil contamination. Because the soil necessitates tilling, runoff controls are necessary to control drainage and erosion. Lime is usually applied from a V-shaped truck bed with a spinner-type propeller in the back (Follett et al., 1981). Uniform spreading is difficult with this equipment, and wind losses can be significant. A more accurate but slower and more costly method is a lime spreader (a covered hopper or conveyor) pulled by a tractor. Limestone does not migrate easily in the soil since it is only slightly soluble, and must be placed where needed. Plowing and/or discing surface-applied lime into the soil may therefore be required.

The application of fluid lime is becoming more popular, especially when mixed with fluid nitrogen fertilizer. The combination results in less trips across the soil, and the lime is available to counteract acidity produced by the nitrogen. Injection of a lime slurry may also be feasible to reach contamination at relatively deep depths.

Cost--

Costs for neutralization are highly dependent on the quantities of materials used to neutralize the waste and the type of materials used for neutralization.

Adsorption

General Description--

Adsorption refers to the process which results in a higher concentration of a chemical (sorbate) at a solid surface (sorbent) or within the pore structure of the sorbent than is present in bulk solution. Actual sorption mechanisms are often not known. Sorption is the major general retention mechanism for many organic compounds and metals onto soils. Adsorbed compounds are in equilibrium with the soil solution and are capable of desorption (Bonazountas and Wagner, 1981).

Several processes are involved in adsorption including:

- ion exchange;
- physical adsorption through weak atomic and molecular interaction forces (van der Waal forces);
- specific adsorption exhibited by anions involving the exchange of the ion with surface ligands to form partly covalent bonds; and
- chemisorption involving a chemical reaction between the compound and the surface of the sorbent.

The effectiveness of utilizing sorption to immobilize a hazardous material can generally be predicted by the compounds adsorption isotherm, which expresses the relationship between the amount of constituent adsorbed onto a solid and the concentration of solute in solution at equilibrium. One frequently used relationship is the Freundlich isotherm, which is:

$$X = kC^N \qquad (3\text{-}1)$$

where: X = amount of constituent adsorbed per unit dry weight of soil,
k and N are constants, and
C = solution phase equilibrium concentration.

The percentage adsorbed under natural moisture conditions can be estimated by:

$$\text{Percent sorbed} = \frac{100}{1 + {\frac{X}{k}}^{1/N} \frac{\theta}{X}} \qquad (3\text{-}2)$$

where: θ = fraction soil moisture content (weight basis).

When adsorption is linear, $N=1$, and the percent sorbed is not a function of the amount sorbed per unit weight of soil (X). However, when adsorption is not linear, the percent adsorbed becomes a function of X. Equation 3-2 shows the percent of chemical adsorbed as a function of k and X.

Materials used for adsorption include various agricultural products and by-products, sewage sludges, activated carbon, and other organics. The organic material can be applied to the soil by harrowing or disking. The amount of organic material which is required to immobilize the hazardous constituent is primarily dependent on the adsorbability of the constituent and the organic content of the soil matrix.

Desorption is also important with respect to treatment effectiveness because of chemical release from soil into percolating water. Generally the extent of desorption also follows the Freundlich isotherm, but with different K and N values. Factors directly associated with desorption include the amount of leachate (soil/water ratio) and the amount of hazardous constituent contaminating the soil (soil/constituent ratio). The extent of desorption will decrease with an increase of these ratios.

Hazardous Constituents Amenable to Treatment--

Heavy metals and organic constituents are amenable to adsorption.

Performance--

Adsorption is a treatment technology which has proven to be effective for the removal of metals or organics. It is, however, only considered as a means of short-term soil remediation since hazardous constituents may slowly desorb with time and, potentially, the sorbent may degrade and result in the release of the hazardous constituents. Conversely, in the case of organic constituents, a sorbent may immobilize the hazardous constituents until they are naturally biodegraded. Repeated application of an adsorbent may be required to provide a high level of performance.

Reliability--

The reliability of adsorbtion to immobilize hazardous constituents in soils is highly dependent on the nature of the constituents and site conditions. Degradation or mineralization of the adsorbent could result in a release of hazardous constituents to the environment. In general, adsorbtion is expected to be moderately reliable over the short term, and somewhat less reliable over the long term.

Implementability--

The implementability of adsorption varies widely depending on site conditions. Sites most suitable for treatment are those which are accessible to heavy equipment and for which the depth of soil contamination is shallow. The organic sorbents can then be easily applied to the surface and tilled into the soil.

Cost--

Costs for adsorption are highly variable due to hazardous constituent type, quantity and sorbent necessary for immobilization.

Stationary/Mobile Rotary Kiln Incineration

General Description--

Rotary kiln incineration has been in use for many years and can be used to destroy contaminated soils from a release at a SWMU. A rotary kiln generally consists of a cylindrical refractory-lined shell mounted at a slight incline (i.e., less than 5 degrees). The shell rotates (5 to 25 times per hour) during the incineration process to control residence times and mixing with combustion air to ensure that maximum destruction is achieved. In most cases, a secondary chamber is used to further the destruction process. However, the secondary unit can be used alone to burn flammable liquids.

There are two basic designs of rotary kilns, the cocurrent and countercurrent designs. The cocurrent design is a unit that has an auxiliary fuel burner at the front end of the incinerator where contaminated soils are fed in. The countercurrent design has the fuel feed at the lower end of the unit, therefore the combustion gases flow countercurrent to the flow of contaminated soils. Each design adequately incinerates hazardous constituents, however the countercurrent design is better suited for constituents with a low heating value (such as saturated material) due to the fact that temperature is controlled at both ends of the unit. This feature tends to minimize overheating of the refractory liner (Bonner, 1981).

Residence times vary from a few seconds for highly combustible gas to a few hours for low combustible solid wastes (i.e. contaminated soils). In dealing with the incineration of various types of hazardous constituents and mediums to which they are attached, the following variables must be adressed (GCA, 1983c):

- size and physical state of the hazardous constituents within the soil,
- chemical characteristics of the hazardous constituents within the soil,
- rate of volatilization,
- rate of ignition,
- feed rate and volumetric heat release,
- kiln dimensions, slope, and rotational speed,
- thermal decomposition and oxidation rate,
- presence of heat sinks such as water or excessive ash,
- slag formation and composition,
- heat losses, and
- secondary chamber configuration and size.

Incineration temperatures can be varied from 800° to 1400°C depending on the heat requirements necessary to incinerate various hazardous constituents in contaminated soils. For example, soils contaminated with dioxins require a temperature of at least 1200°C to ensure adequate destruction (destruction and removal efficiency - DRE = 99.9999%).

The rotary kiln incineration method is used at three of the largest commercial incineration facilities (Rollins Environmental Systems in Deer Park, Texas; Environmental Systems Company (ENSCO), El Dorado, Arkansas; and SCA Chemical Services in Chicago, Illinois). Table 3-11 shows some of the major advantages and disadvantages pertaining to the use of a rotary kiln.

Mobile rotary kiln incinerators are also used for the destruction of contaminated soils. These systems consist of flat-bed mounted units that can be trucked to a site for onsite incineration. The EPA-ORD mobile incinerator has recently undergone a test burn for the destruction of contaminated soils, while the ENSCO mobile rotary kiln is currently undergoing active testing.

Hazardous Constituents Amenable to the Technology--

Essentially all organic types of constituents in soils including PCBs and dioxins can be incinerated by using a rotary kiln (Bonner, 1981). There are, however, hazardous constituents such as heavy metals, high moisture content wastes, inert materials, inorganic salts, and the general group of wastes that have high inorganic content that are unlikely candidates for incineration (Bonner, 1981).

Performance--

The previously listed commercial land-based incinerators are a very effective means of destroying contaminated soils. Each incinerator can handle various RCRA wastes, however, only the Rollins incinerator is permitted to burn PCB-contaminated soils.

The mobile EPA-ORD unit has been tested on dioxin soil in Missouri and has the capability of burning soils at a rate of 2,000 lb/hr (Hasel, 1985). EPA has reported a successful test burn of dioxin soils to a destruction level of 99.9999% (Hasel, 1985). ENSCO has reported that they have two units capable of incinerating soils and are constructing a third. These units are expected

TABLE 3-11. ADVANTAGES AND DISADVANTAGES ROTARY KILN INCINERATOR

Advantages

1. Can incinerate a wide variety of liquid and solid hazardous wastes.
2. Can incinerate materials which are passing through a melt phase.
3. Capable of receiving liquids and solids independently or in combination.
4. Capable of receiving drums and bulk containers.
5. Adaptable to wide variety of feed mechanism designs.
6. Characterized by high turbulence and air exposure of solid wastes.
7. Continuous ash removal which does not interfere with the waste oxidation.
8. No moving parts inside the kiln (except when waste transport chains are added).
9. Adaptable for use with a wet gas scrubbing system.
10. Retention or residence time of the nonvolatile component can be controlled by adjusting the rotational speed.
11. Waste can be fed directly into the kiln without any preparation (such as preheating, mixing, etc.).
12. Can be operated at temperatures in excess of 1400°C (2500°F), making them well suited for the destruction of toxic compounds that are difficult to thermally degrade.
13. Rotational speed control of the kiln also allows a turndown ratio (maximum to minimum operating range) of about 50 percent.

Disadvantages

1. High capital cost for installation.
2. Operating care necessary to prevent refractory damage; thermal shock is a particularly damaging event.
3. Airborne particles may be carried out of kiln before complete combustion.
4. Spherical or cylindrical items may roll through kiln before combustion is completed (insufficient residence time).
5. Frequently requires additional makeup air due to air leakage via the kiln end seals.
6. Drying or ignition grates, if used prior to the rotary kiln, can cause problems with melt plugging of grates and grate mechanisms.
7. High particulate loadings to air pollution control equipment.
8. Relatively low thermal efficiency.
9. Maintenance of seals at either end of the kiln; a significant operating difficulty.
10. Formation of clinker or ring residue on refractory walls, due to drying of aqueous sludge wastes or melting of some solid wastes.

Source: Bonner, 1981.

to have RCRA permits by the end of the year for soil incineration. One unit is in Florida burning liquids and sludge while the other is being readied for a test burn on dioxins in Arkansas.

Reliability--

Rotary kiln units both mobile and stationary have been used successfully to incinerate and thus, destroy various types of contaminated soils.

Implementability--

Stationary incinerators are readily implementable for the destruction of contaminated soils since incineration facilities are available. However, concerns such as the ability to excavate the contaminated soils and haul distances must be considered. Long haul distances and difficult excavation will greatly increase the costs and time needed to destroy the soils.

Implementability is of greater concern when using a mobile incinerator in that, in addition to excavation concerns, issues pertaining to the incinerator location and space (land) requirements at specific sites must also be considered. If incineration is to occur in a residential-type area, issues concerning public health and safety must be considered.

Cost--

Stationary incinerator costs were reported by Rollins at \$.65 to \$.75/lb (Murphy, 1985). SCA, Inc., which requires soils to be placed in 150 to 200 lb fiber or plastic bags, reported costs of \$.35 to \$.40/lb (Mullen, 1985). These costs include post-incineration handling of the various residues. However, these costs do not include excavation or hauling thereby greatly increasing the cost of incineration.

Costs for incineration with a mobile unit were reported from ENSCO as being \$400 to $\$500/yd^3$ (Lanier, 1985). A consideration with onsite incineration is that residues must be disposed of properly after incineration. The various options depend on how the residue is classified, i.e. hazardous vs. nonhazardous (delisted). The options consist of using the residue as an onsite construction waste, disposal in a sanitary landfill or in an approved RCRA landfill. There is a wide variation between these options, thereby resulting in a wide variation in disposal costs.

IMMINENT TECHNOLOGIES

Storage Vaults

General Description--

This type of corrective action strategy is a fairly new technology and to date has not acquired the appropriatre RCRA permits. It may, however, prove to be an acceptable method for long-term storage of contaminated soils. Rollins Environmental Services has developed a vault to contain hazardous wastes or soils with an expected useful life of approximately 50 years. The vaults are very much like an above-grade landfill except it uses lined concrete retaining walls to contain the soils. The basic components of the vault consist of:

- an umbrella cap,
- storm water collection system,
- cap monitoring system,
- secondary cap,
- lined concrete containment walls,
- drain protective layers,
- leachate collection system,
- primary liner,
- leachate monitoring system,
- secondary liner, and
- a clay or concrete tertiary liner.

Like a double-lined landfill the vault appears to have sufficient layering to adequately contain the soils in conjunction with the leachate collection/detection systems.

Applicability--

These vaults may be quite effective in containing contaminated soils but at this time have limited demonstrated performance and are only recognized by the EPA as a temporary storage unit. Rollins reports that the vaults can be installed essentially anywhere, as long as soils are stable enough to support the structure. Sizes can range from 10 to 30 ft high walls and cover one half to 25 acres or more. Rollins also reports that organic sludges, soils, and contaminated equipment can be safely disposed of in these vaults.

Mobile Hazardous Waste Extraction from Excavated Soils

General Description--

This is a new and emerging technology that is being sponsored by the EPA. There is a unit available at this time that is capable of decontaminating soil at a rate of 3 to 5 yd^3/hr. The goal of this project is to be able to "scrub" soils clean enough so they can be redeposited in the place from which they were excavated.

The system generally consists of a hydraulically lifted bucket, feed hopper, and soil metering paddle that places the soil into the unit. The soils are then washed or "scrubbed" with water and/or additives for hazardous constituent removal. The unit contains various screens and water knives for scrubbing purposes, along with rinsing areas and hydrocyclones for dewatering. Once soils are completely rinsed, dewatered, and dried they may be returned to the excavation area. Water and additives are collected and reused to keep operating costs down.

Applicability--

It is reported that fine clays cannot be effectively "scrubbed", however, small particles greater than 2 mm can be cleaned in this process. Also, most inorganic compounds, most water soluble or readily oxidized organic chemicals and some partially miscible-in-water organics can be treated with water or water plus an additive (Milanowski and Scholz, 1983).

EPA reported that the unit has successfully removed lead from soils, however the unit did have a number of operation problems in the field and is presently being retrofitted (Traver, 1985). Prior to this, laboratory experiments on phenols, arsenic trioxide, and PCBs in two soil matrices of sand/gravel/silt/clay and organic loam were completed and found to be quite successful. If further testing is performed on the applicability of this unit, it may prove to be a very effective method of treating releases to soils from all types of SWMUs.

Fluidized-Bed Incineration

General Description--

A fluidized-bed incinerator consists of a vertical refractory-lined cylinder that contains a bed of inert, granular material which usually consists of sand. The diameter of the units normally ranges from a few meters to 15 meters (GCA, 1983c). Temperatures for incineration are normally 450° to 980°C (Bonner, 1981) and are limited by the softening point of sand which is 1100°C. The sand bed particles are fluidized by blowing low velocity air upward through the medium. This rate of air movement is a direct relation to particle size and acts to suspend the bed in a fluid-like manner.

Hazardous waste materials including liquids, slurries, gases, sludges, and contaminated soils can be incinerated with the fluidized bed. However, hazardous constituents such as sludges or contaminated soils must be pretreated involving sorting, drying, shredding, and special feed considerations (Bonner, 1981). Generally, as with the rotary kiln, the fluidized bed can incinerate most hazardous constituents. However, the fluidized bed does necessitate the use of an after-burner since hazardous constituents are volatilized from the soil in the main unit and then destroyed in the vapor phase by the after-burner. This occurs due to the low operating temperatures of this type of incineration. Table 3-12 lists advantages and disadvantages of the fluidized-bed incinerator.

A recently developed circulating fluidized-bed incinerator by G.A. Technologies of San Diego, California involves the use of the contaminated soil as the bed material and uses an air flow of 3 to 5 times as great as that in conventional systems. The increased air flow also increases the turbulence which makes for a more turbulent combustion environment. This allows the use of lower temperatures and precludes the use of an after-burner.

TABLE 3-12. ADVANTAGES AND DISADVANTAGES OF FLUIDIZED-BED INCINERATION

Advantages

1. General applicability for the disposal of combustible hazardous solids, liquids, and gaseous wastes.
2. Simple design concept, requiring no moving parts in the combustion zone.
3. Compact design results from high heating rate per unit volume (100,000 to 200,000 Btu/hr-ft^3 (900,000 to 1,800,000 kg/cal/hr-m^3)) which results in relatively low capital costs.
4. Relatively low gas temperatures and excess air requirements which tend to minimize nitrogen oxide formation and contribute to smaller, lower-cost emission control systems.
5. Long incinerator life and low maintenance costs.
6. Large active surface area resulting from fluidizing action enhances the combustion efficiency.
7. Fluctuation in the feed rate and composition are easily tolerated due to the large quantities of heat stored in the bed.
8. Provides for rapid drying of high-moisture-content material, and combustion can take place in the bed.
9. Proper bed material selection supresses acid gas formation; hence, reduced emission control requirements.

Disadvantages

1. Difficult to remove residual materials from the bed.
2. Requires fluid bed preparation and maintenance.
3. Periodic feed must be selected to avoid bed degradation caused by corrosion or reactions.
4. May require special operating procedures to avoid bed damage.
5. Operating costs are relatively high, particularly electric power costs.
6. Possible operating difficulties with materials high in moisture content.
7. Formation of eutectics (compounds with low melting or fusion temperatures) is a serious problem.
8. Hazardous waste incineration practices have not been fully developed.
9. Not well suited for irregular, bulky wastes, tarry solids, or wastes with a fusible ash content.

Source: Bonner, 1981.

Applicability--

The circulating fluidized-bed incinerator is reported to be a transportable unit however, it was stated that large amounts of soil would have to be incinerated in order for a move to be made. It was also reported that a test burn on PCB soils has been completed and preliminary results show a very high level of destruction (G.A. Technologies, 1985). The unit that was used in the test burn is a 16-in. inside diameter unit with the capability of destroying 500 to 1,000 lb/hr. G.A. Technologies also stated that if the burn proves to be successful a commercial unit with five times the capacity could be constructed very shortly.

Mobile Advanced Electric Reactor

General Description--

The advanced electric reactor, often referred to as a high-temperature fluid wall reactor, uses radiant energy to destroy organic constituents by pyrolysis (chemical decomposition) at high temperature. The radiant energy which is produced by six electrically heated carbon electrodes is focused on the waste through a porous ceramic core. The electrodes are heated to approximately 400°F.

Soils that are fed into the unit must be nonflowing, nonagglomerating and smaller than 100 mesh (Thagard Research Corporation, 1984). However, it is expected that 10 mesh soils will be acceptable. Soils are fed through the top of the reactor and fall through the core. Residence times for 100 mesh solids are reported to be one-tenth of a second for a 30-ft high reactor.

Thagard Research has built a 12-in. diameter mobile unit for Vulcan Associates. The system is truck-mounted and can incinerate 40 tons of soil per day. However, test results are not available for this unit.

J.M. Huber has a 12-in. immobile unit and a 3 in. mobile pilot-scale unit. The 12-in. reactor has successfully incinerated PCB-contaminated soils and the 3-in. reactor has also destroyed dioxin-contaminated soils at Times Beach, Missouri.

Applicability--

This type of reactor can destroy essentially all types of hazardous constituents including soils contaminated with PCBs and dioxins. However, Huber may sell the license or shelf the technology until it is more applicable (Huber, 1985).

Attenuation

General Description--

This technology generally consists of mixing contaminated soils with clean soils to reduce concentrations of the hazardous components to acceptable levels. It can be done only in the upper soil levels and can consist of mixing subsoil, uncontaminated soil from another area of the site or purchased soil with the contaminated soils.

Applicability--

Attenuation is reported to be viable only in the upper 2 ft of soil (i.e., that within the plow layer). It is useful in the attenuation of metals and organics although this technology has only been reported to work well with metals (EPA, 1984b). This technology's implementation is dependent upon site/soil trafficability considerations and depth of contamination. Other issues that must be considered are increased erosion of tilled area, therefore requiring runon/runoff controls and possible alteration of soil horizon characteristics which may allow increased mobility of the hazardous constituents. This technology is reported to have had some field applications (EPA, 1984b).

Chemical Oxidation

General Description--

Chemicals naturally undergo reactions in soil that may transform them into more or less toxic products, or which may increase or decrease their mobility within the soil system. Chemical treatment of contaminated soils entails the reaction of hazardous constituents with reagents, resulting in products which are less toxic, or which become immobilized in the soil column. These reactions may be classified as oxidation reactions, reduction reactions, and polymerization reactions. Oxidation reactions are discussed at this point, reduction reactions will be discussed subsequently and polymerization will not be presented because it has not yet been field tested.

Chemical oxidation is a process in which the oxidation state of an atom is increased. This is accomplished by the transfer of electrons from the atom to an election acceptor such as oxygen. Chemical oxidation represents a significant treatment process in soil systems. As a result of oxidation, a substance may be transformed, degraded, and/or immobilized in soil. Oxidation of hazardous organic constituents in soil can be an effective method of environmental degradation. Oxidation of heavy metals, with the exception of arsenic however, is not usually desirable because heavy metals become more mobile at higher oxidation states. Oxidation reactions within the soil matrix may occur through management of the natural processes in a soil, or through addition of an oxidizing agent.

In the natural soil environment, it is the role of the soil to provide electron acceptors for the oxidation of organics and other compounds. Oxygen is usually the electron acceptor. However, when oxygen is not available, other reducible compounds such as nitrate, Mn(IV), M(III), Fe(III), and S(VI) can function as electron acceptors. Typically, oxidation will occur in soil systems where the redox potential (ability to accept electrons) of the soil is greater than that of the hazardous constituent (i.e., 0.8V). It is important to note that hazardous chemical constituents are more extensively oxidized in less-saturated soils. Therefore, soil moisture control is desirable in promoting natural oxidation processes.

Oxidizing agents may be utilized to degrade organic constituents in soil systems. Oxidation reactions are usually limited in application due to their substrate specificity and pH dependence. Common oxidizing agents considered for in-place treatment include ozone, hydrogen peroxide, and chlorinate (hypochloriate). The latter, however, is not desirable for in situ oxidation of contaminated soil because it can lead to undesirable chlorinated by-products. The relative oxidizing ability of these chemicals compared with other well-known oxidants is indicated in Table 3-13. A serious potential limitation to the use of oxidizing agents for soil treatment is the additional consumption of the oxidizing agent(s) by nontarget constituents in the soil.

In some instances hydrogen peroxide and ozone have been used simultaneously to degrade compounds which are refractory to either material individually. When ozone is the oxidant used, the pH of the soil must be

TABLE 3-13. RELATIVE OXIDATION POWER OF OXIDIZING SPECIES

Species	Oxidation potential volts	Relative oxidation power
Fluorine	3.06	2.25
Hydroxyl radical	2.80	2.05
Atomic oxygen	2.42	1.78
Ozone	2.07	1.52
Hydrogen peroxide	1.77	1.30
Perhydroxyl radicals	1.70	1.25
Hypochlorous acid	1.49	1.10
Chlorine	1.36	1.00

Source: EPA, 1984b.

carefully controlled since the rate of decomposition of ozone is strongly influenced by pH. At high pH direct reactions between ozone and the hazardous constituents in the soil are reduced. When hydrogen peroxide is used, the metal content of the soil must be considered because metals act as catalysts causing autodecomposition of peroxide. The result will be an increase in the soil dissolved oxygen but no direct oxidation of hazardous constituents by the peroxide.

One problem common to strong oxidants in general is their ability to oxidize the natural organic matter in the soil which often acts as sorption sites for organic constituents, resulting in decreased sorption capacity in soils for some organics. Therefore, some hazardous constituents' mobility may be increased. Nevertheless, successful field application of strong oxidants has been completed. Examples of *in situ* oxidation of contaminated soils using ozone are provided in Nagel et al., 1982.

Applicability--

General characteristics of organic chemicals likely to undergo oxidation include: (1) aromaticity, (2) fused ring structures, (3) extensive conjugation, and (4) ring substituent fragments. Certain compounds are more oxidizable in soils that others. The reactivity of organic chemical classes with respect to chemical oxidation is summarized in Table 3-14.

For natural oxidation of hazardous constituents at soil surfaces, water soluble organic substances with half-cell potential below the redox potential of a well-oxidized soil are needed. Chemical constituents which do not oxidize at soil surfaces are given in Table 3-15.

For in situ oxidation by addition of ozone as an oxidizing agent, the following reactivity trends apply: (1) phenol, xylene, toluene, benzene, and (2) dichtoro-, trichloro-tetrachlorophenol, pentachlorophenol. Constituents not readily oxidized by ozone include:

- inorganic compounds in which cations and anions are in their highest oxidation state;
- organics which are highly halogenated; and
- saturated aliphatic compounds which do not contain easily oxidized functional groups, i.e., aliphatic hydrocarbons, aldehydes, and alcohols.

TABLE 3-14. OXIDATION REACTIVITY FOR ORGANIC CHEMICAL CLASSES

High	Moderate	Low
Phenols	Alcohols	Halogenated hydrocarbons
Aldehydes	Alkyl-substituted aromatics	Saturated aliphatic compounds
Aromatic amines	Nitro-substituted aromatics	Benzene
Certain organic sulfur compounds	Unsaturated alkyl groups	Chlorinated insecticides
	Aliphatic ketones	
	Aliphatic acids	
	Aliphatic esters	
	Aliphatic amines	

JRB Associates, 1982.

Source: Compiled by EPA, 1984b.

TABLE 3-15. SOME CHEMICALS THAT DO NOT OXIDIZE AT SOIL AND CLAY SURFACES

Chemical Name

Acetamide
Acetone, anisilidene-
-,dianisilidene-
-,dicinnamylidene-
-,dibenzylidene-
ß-Carotene
Cyclohexylamine
Monoethanolamine
Triethylamine

Dragun and Helling, 1982.
Source: Compiled by EPA, 1984b.

Pesticides such as aldrin, heptachlor, DDT, parathion, and malathion are oxidized to other hazardous compounds and are, therefore, not suited to such treatment.

Oxidation with hydrogen peroxide has been demonstrated for cyanide, aldehydes, dialkyl sulfides, dithionate, nitrogen compounds, phenols, and sulfur compounds. Chemical groups incompatible with peroxide oxidation due to their resultant increased mobility are given in Table 3-16.

TABLE 3-16. CHEMICAL GROUPS THAT REACT WITH PEROXIDES TO FORM MORE MOBILE PRODUCTS

Acid chlorides and anhydrides
Acids, mineral, nonoxidizing
Acids, mineral oxidizing
Acids, organics
Alcohols and glycols
Alkyl halides
Azo, diazo compounds, hydrazine
Cyanides
Dithio carbamates
Aldehydes
Metals and metal compounds
Phenols and cresols
Sulfides, inorganic
Chlorinated aromatics/alicycles

Source: EPA, 1984b.

Soil-catalyzed oxidation reactions have been tested in the field for several chemical classes. However, factors such as aeration of the soil and soil moisture effect the level of treatment attainable.

The use of oxidizing agents is not that well tested in soil systems but have been used in wastewater treatment. Care must also be taken since oxidizing agents can cause violent reactions when used in conjunction with metals and also, soil hydraulic properties may be greatly affected, particularly in a structured soil.

Chemical Reduction

General Description--

Chemical reduction is a process in which the oxidation state of an atom is decreased. Reducing agents are electron donors, with reduction accomplished by the addition of electrons to the atom. Reduction of chemicals may occur naturally within the soil system. Certain compounds are more susceptible to reduction than others because they will accept electrons. Addition of reducing agents to soil to degrade reducible compounds can be used as an in-place treatment technology for organics, chromium, selenium, and sodium.

Chemical reduction using catalyzed metal powders and sodium borohydride has been shown to degrade toxic organic constituents. Reduction with catalyzed iron, zinc, or aluminum affect treatment through mechanisms including hydrogenolysis, hydroxylation, saturation of aromatic structures, condensation, ring opening, and rearrangements to transform toxic organics to innocuous forms.

The use of catalyzed metal powders, though used successfully for aqueous solutions passed through beds of reactant diluted with an inert solid (Sweeney, 1981), has not been demonstrated in the soil environment. However, small-scale field experiments of chemical reduction of organic constituents in soils with sodium borohydride and zinc have been successful. Results of reductive treatment for degradation of paraquat in soil are summarized in Table 3-17. Results indicate that sodium borohydride and powdered Zn/acetic acid combinations achieved very effective degradation of paraquat in soil and sand media.

TABLE 3-17. CHEMICAL REDUCTIVE TREATMENT FOR DEGRADATION CF PARAQUAT IN SOIL

Chemical	Paraquat in soil (ppm)		
Treatment	Initial (1 day)	4 Months	Comment
None	9,590	6,300	-
$NaBH_4$-soil	None detected	None detected	Violent foaming
$NaBH_4$-sand	None detected	None detected	No foaming
Powdered Zn acetic acid	60	69	Some bubbling

Staiff et al., 1981.
Source: Compiled by EPA, 1984b.

Hexavalent chromium Cr(VI) is highly toxic and mobile in soils and must be reduced to trivalent chromium Cr(III) which is far less mobile and toxic. The reduction can be accomplished by adding acidification agents such as sulfur and reducing agents such as leaf litter, acid compost, or ferrous iron. These additives are not always necessary if sufficiently acidic soil conditions are present whereby the reaction will occur naturally. After reduction, Cr(III) is precipitated via lime addition; Cr(III) precipitates over a pH of 4.5 to 5.5. Caution is required, however, since trivalent chromium can be oxidized to Cr(VI) under conditions prevalent in many soils, i.e., under alkaline and aerobic conditions in the presence of manganese. With the exception of lime addition, the above also holds true for hexavalent selenium reduction to either selenite (Se(IV)) or elemental selenium Se^0 which are far less mobile. It is important to note, however, that selenite (Se(IV)) is an anion which leaches at high pH and thus, selenium could not be treated if increased pH were required as part of the treatment for other metals.

Applicability--

Soils contaminated with chlorinated organics, unsaturated aromatics and aliphatics, miscellaneous other reducible organics, hexavalent chromium, and hexavalent selenium (when significant amounts of other metallic constituents are not present) are treatable by chemical reduction.

The achievable level of treatment is potentially high for hazardous constituents susceptible to reduction, and for limited areas of contamination. The soil must be without large quantities of competing constituents susceptible to reduction, or the level of treatment may be greatly decreased.

The use of reducing agents for organic constituents may also degrade soil organic matter. The extent of impact on soils is not known at the present time. The products of reduction may present problems with respect to toxicity, mobility, and degradation however, this information is not presently available. Iron reductants appear to be the least damaging to soil systems, though iron has a secondary drinking water standard and is of concern with respect to aesthetics. Addition of metals with acetic acid may possibly increase metal mobility by decreasing soil pH. Addition of sodium borohydride may adversely impact soil permeability, depending on the type and content of clay and ionic constituents in the soil solution.

It is reported that this technology may not be able to treat soils to acceptable levels during initial treatment, therefore necessitating a second round of treatment.

Extraction (Soil Flushing)

General Description--

This technology involves the removal of hazardous constituents from the soil horizon by flooding the site with a flushing solution and collecting the elutriate in shallow wells to prevent migration and further contamination to soils and ground water. Flushing solutions can include water, acidic aqueous solutions (sulfuric, hydrochloric, nitric, phosphoric, and carbonic acid), basic solutions (e.g., sodium hydroxide), and surfacants (e.g., alkylbenzene sulforate). Once the soils have been properly flushed and the elutriate collected it can then be put through a treatment system and disposed. Sampling and analysis would then be necessary to ensure that the contamination has been removed and also to ensure that the flushing solution has been adequately removed.

Another development in this technology by the EPA is a mobile in situ containment/treatment system. It generally consists of grout injection to isolate the contaminated area; grout must be effective in the soil of concern and be compatible with the hazardous constituents in the soil. The area is then flushed with either water or appropriate additives to remove contamination. This unit is reported to have the capability of treating an area of approximately 80,000 ft^2. At the present time the unit is being prepared for a field test (Fall 1985) at Air Force property in Wisconsin on a solvent spill; this will be its first field test (Traver, 1985).

Applicability--

This technology is in initial stages of development. However, the mobile unit or a stationary setup at a site may in the near future prove to be a viable technology for remediation of releases to soils. Much of research at this time is going towards the development of solvents or flushing agents that can adequately and safely remove hazardous constituents from soils.

In general, water can be used to extract water-soluble or water-mobile constituents; acidic solutions can be used to recover metals and basic organic constituents; and basic solutions can be used for removal of metals and some phenols. At present, this technology is not implementable at a site. However, after the slated field test of EPA's mobile unit it may be a viable corrective measure.

Multiple-Hearth Incineration

General Description--

A multiple-hearth incinerator generally consists of a refractory-lined circular steel shell, a control shaft that rotates, a series of solid flat hearths, a series of rabble arms with teeth in each hearth, an air blower, wall-mounted fuel burners, an ash removal system, and a waste feeding system (Bonner, 1981). There are also side ports for fuel injection, liquid waste burners, and an after-burner is generally necessary for soil incineration.

Applicability--

The multiple-hearth incinerator while designed to incinerate sewage and hazardous type sludges may also be used to treat contaminated soils, given sufficient pretreatment to attain a constant size and moisture content.

Due to the low temperatures used during incineration, contaminated soils usually require the use of an after-burner to achieve complete destruction. Devolatilization is realized in the main chamber with the gaseous phase being destroyed in the after-burner.

Generally the same types of hazardous constituents that can be incinerated with a rotary kiln can also be destroyed with a multiple-hearth incinerator. Some unlikely candidates for multiple-hearth incineration consist of uncombustible hazardous constituents such as heavy metals, inert material, inorganic salts, and generally substances with high organic content. In general, the multiple-hearth incinerator is not expected to be as effective as the rotary kiln-type incinerator.

SECTION 4

CASE STUDIES

INTRODUCTION

GCA conducted a search for case studies which would demonstrate how to select and implement corrective measures for releases to soils from SWMUs. Approximately 100 sites were reviewed to develop a list of sites for potential case study analysis. Information was obtained from several data sources including EPA Headquarters, EPA Regional offices, and literature searches.

The site review focused on finding examples of sites where remedial responses were either ongoing or completed. Site Selection Worksheets were completed for sites which met this initial criteria. The worksheet (shown in Figure 4-1) contained information which was used to screen the sites for potential case study evaluations.

The criteria used for final selection of case studies included:

- availability and completeness of site information and monitoring data;
- type of remedial measures implemented;
- types of wastes and hazardous constituents present at the facility;
- site characteristics;
- geographic locations; and
- waste management practices.

In reviewing potential case studies, those case studies that were designated as being most representative of a variety of the above criteria and constituents of each criterion were selected.

SITE NAME

LOCATION

TYPE OF FACILITY

SIZE OF SITE/DISPOSAL AREA

YEARS OF OPERATION/DISCOVERY OF RELEASE (How & when release discovered)

TYPES OF RELEASES

TYPE OF WASTE DISPOSED/HAZARDOUS CONSTITUENTS PRESENT

MEDIA CONTAMINATED

CLIMATE

TOPOGRAPHY

SOILS

Figure 4-1. Worksheet for screening case studies.

GEOLOGY

HYDROLOGY (Ground Water & Surface Water)

RESPONSE ACTIONS (Including Designed and Implemented)

MONITORING DATA AVAILABLE

SUCCESS/FAILURE OF REMEDIATION (Removal Efficiency, Containment Effectiveness)

Figure 4-1 (continued)

A list of the selected sites and a summary of the remedial responses at these sites is presented in Table 4-1. Case studies were prepared using the outline shown in Figure 4-2. These case studies are presented below.

FAIRCHILD REPUBLIC COMPANY - HAGERSTOWN, MARYLAND

Facility Description

The Fairchild Republic Company used chemical solutions to clean sheet aluminum that is used in the manufacture of airplanes. Between 1950 and 1967, waste sludges and liquids from the cleaning processes were disposed in an open landfill. The landfill had an irregular shape with a maximum length of about 160 ft and a refuse depth of about 5 ft.

During the mid-1960s, an improved waste treatment plant was constructed which enhanced the removal of heavy metals through chemical addition. The concentrated sludge was dewatered through filter presses and placed in several permitted, clay-lined sludge lagoons. The sludge was subsequently hauled to a licensed disposal facility. After trivalent chromium was declassified as a hazardous substance, the trivalent chromium sludge was disposed in a local sanitary landfill.

As a result of these disposal practices, the surrounding soil and the underlying ground water became contaminated with chromium and organic chemicals.

Site Characteristics

Climate--

Climate in the area of the site is continental. Average temperatures range from 21°F (late January to early February) to 88°F (late July). Annual precipitation averages 37.08 in. (1953 to 1983), and is generally evenly distributed throughout the year.

Soils--

The soils at the site consist of silty clay loam in the Hagerstown-Diffield-Frankstown Association. These soils are generally classified as reddish, well-drained, deep and medium textured.

TABLE 4-1. TYPES OF RELEASE(S) AND REMEDIAL RESPONSE(S) IMPLEMENTED AT SELECTED SITES

Site Name/Location	Type of Facility	Hazardous Constituents Present	Type(s) of Releases	Remedial Response
1. Fairchild Republic Company/ Hagerstown, Maryland	Open landfill (350 ft x 160 ft x 515 ft) used for disposal of waste sludge from plant operations.	Heavy Metals, miscellaneous organic solvents (Cr, Cu, Zn, Al, TCE, Xylenes, Toluene, methyl chloride, ethyl benzene, 1,1-dichloroethylene).	Ground water, soils	• Removal of contaminated materials (excavation) • Backfilling • Capping • Grading, topsoil, and seeding
2. Whitmoyer Laboratories/ Myerstown, Pennsylvania	Wastewater generated by the manufacturing plant treated with lime; slurry disposed in an unlined lagoon.	Arsenic (inorganic and organic).	Ground water, surface water, soils	• Excavation of contaminated sludges and soils • Concrete storage bins • GW treatment and recovery (counter pumping)
3. Enterprise Avenue/ Philadelphia, Pennsylvania	City of Philadelphia landfill used for the disposal of industrial wastes.	Volatile organics, metals, organic halides.	Ground water, soils	• Excavation of contaminated soils • Offsite disposal/treatment • Backfilling • Capping • Grading, topsoil, seeding
4. Frontenac Site/ Frontenac, Missouri	Storage tank area used for waste oils and chemical wastes.	2,3,7,8-TCDD (dioxin), PCBs, 1,2-trans-dichloroethylene, tetrachloroethane.	Soils, sediments	• Asphaltic concrete cap over gravel subgrade • Toe-trench filled with rip-rap rock • Wire cable/steel stakes fence around site
5. Crystal Chemical/ Houston, Texas	Landfill, 5-acres used for wastes from herbicide manufacturing process.	Arsenic, phenols.	Soils (89,000 yd^3), ground water, surface water (from runoff)	• Contaminated water (from flooding) was removed • Equipment and buildings removed • Waste pits filled in • 1-2 in. temporary clay cap and plastic cover installed • Proposed: permanent capping, in situ treatment, and slurry wall
6. Silresim/ Lowell, Massachusetts	Chemical reclamation facility (5-acre).	Volatile organics, PCBs, pesticides, some metals.	Ground water, soils, surface runoff	• Construction of berms and placement of absorbent fill material in trenches • Removal of drums and chemicals in bulk storage • Removal of buildings and containers • Installation of 2 ft compacted clay cap with gas venting system

I. FACILITY DESCRIPTION

- A. TYPE OF SWMU/SYSTEM DESIGN (Including any leak detection and/or monitoring system)
- B. YEARS OF OPERATION
- C. TYPE OF WASTES RECEIVED/DISPOSED
- D. SIZE OF SITE/DISPOSAL AREA
- E. ANY PREVIOUS OPERATIONS AT THE SITE/SITE BACKGROUND
- F. REGULATORY & LEGAL STATUS (NPL,CERCLA,etc.)

II. SITE CHARACTERISTICS

- A. CLIMATE
- B. TOPOGRAPHY
- C. SOILS
- D. GEOLOGY
- E. HYDROLOGY (Ground Water & Surface Water)

III. RELEASES

- A. TYPES/CAUSES OF RELEASES
- B. MECHANISMS FOR DETECTION (Include how & when release was detected)
- C. EXTENT OF CONTAMINATION & HAZARDOUS CONSTITUENTS PRESENT (Include media contaminated, and area or volume of contamination)

IV. REMEDIAL ACTIONS

- A. RESPONSE
  - 1. IMPLEMENTED
  - 2. UNDER CONSTRUCTION
  - 3. DESIGNED/CONCEPTUALIZED
  - 4. MONITORED/TESTED
- B. SUCCESS/FAILURE OF REMEDIATION (Include summary of results from available monitoring data)

Figure 4-2. Outline for case studies write-up.

Geology--

The bedrock underlying the site is composed of limestone with numerous fractures and cavities. The stratigraphy of the bedrock is a series of parallel folds with the axial traces trending N 15° E, and the joint measurements trending in two directions: strike N 80° E, dip 85° NW, and strike W 5° E, dip 60° SE.

Hydrology--

A carbonate aquifer lies beneath the site, with the water table ranging from 34.1 ft below the surface (during dry fall months) to 11.4 ft below the surface (during wet winter months).

Releases

Types/Causes of Releases--

As a result of rainfall and surface water percolating through the sludge, the surrounding soil and ground water became contaminated with chromium and organic chemicals. Additionally, hazardous constituents released to ground water migrated to nearby domestic water wells.

Mechanisms for Detection--

Fairchild Republic Company had a State permit to operate two onsite sludge lagoons, which expired in 1978. Prior to reissuing a permit for the lagoons, the Maryland Department of Natural Resources, Water Resources Administration (WRA) conducted ground water monitoring activities (in August 1978). WRA's monitoring results revealed high levels of chromium contamination approximately 400 ft away from the sludge lagoons. The source was determined to be the nearby open landfill containing chromium sludge.

Extent of Contamination--

The major hazardous constituents found at the site included heavy metals (such as chromium, copper, zinc, and aluminum), and organic compounds (such as 1,1,1-trichloroethane, 1,1-dichloroethylene, ethylbenzene, methylchloride, toluene, trichloroethylene, and xylenes). Chromium was found to be the dominant hazardous constituent present at the site with total chromium concentrations ranging from 20 mg/kg to 280,000 mg/kg with the natural background level of total chromium in the range of 50 to 100 mg/kg.

The estimated volume of material in the waste disposal area is 5,400 yd^3. Approximately 50 percent of this material was determined to be contaminated soils, with the remainder being only partially contaminated. Contaminated materials were found to be near or directly on the bedrock in some areas.

Remedial Actions

Response--

Contaminated soils were excavated down to the bedrock (determined by State inspectors to be the practical limit for excavation). Composite soil samples were then collected from the excavated area. Subsequent analyses indicated that the total and hexavalent chromium levels were within EPA standards.

Remedial measures were continued by placing a layer of compacted clay approximately 2 ft thick directly over the exposed bedrock to inhibit the infiltration of precipitation. The pit was then backfilled with clean soil and crushed rock and then compacted.

A clay cap was installed over the site area. The cap was graded to allow runoff and to minimize surface ponding (thereby decreasing the amount of vertical infiltration of precipitation and contaminants). A perimeter drain was installed around the facility to further minimize the movement of runoff water onto the site. A topsoil cap of approximately 6 to 8 in. was placed over the clay layer and seeded with a grass-legume mixture to mitigate erosion of the clay layer and to further inhibit water infiltration (by evapotranspiration).

Continued monitoring of the site is being performed, using wells previously installed, to determine the long-term effects of the response actions.

Success/Failure of Remediation--

The remedial actions taken appear to have been effective in reducing the chromium constituents. Ground water monitoring wells have shown a continual decrease in chromium levels. Limited monitoring data is available for organic contamination and therefore, the effectiveness of the organics removal cannot be adequately evaluated at this time. The volatile organics found on the site are generally highly soluble and very mobile in water. However, most of these should volatilize, degrade chemically or biologically, or be diluted in the ground water over time.

While the percolation of precipitation has been virtually eliminated, the variation of ground water elevation has not been controlled. Fractured bedrock zones remain contaminated with precipitated heavy metals. The precipitation of heavy metals is enhanced by limestone and dolomite bedrock because of the high pH associated with these formations. However, rising ground water levels will lower the pH conditions, causing the metal precipitates to become dissolved in the ground water and potentially transporting them through the ground water regime.

Reference: U.S. EPA, 1984a.

WHITMOYER LABORATORIES - MYERSTOWN, PENNSYLVANIA

Facility Description

Beginning in 1934, and continuing to the present, Whitmoyer Laboratories has operated a pharmaceutical manufacturing facility at the site. Until 1964, wastewater generated by the manufacturing processes was treated with lime and handled as a slurry. The wastewater slurry was then disposed in an unlined lagoon.

Site Description

Climate--

The average annual precipitation in the site area is 44 in. Average annual snowfall is 35 in. Average temperatures range from 30°F (January) to 76°F (July) with an annual average of 53°F. The average windspeed is 7.7 mph.

Soils--

Soils overlying the site consist of a 5 to 7 ft thick layer of alluvial sand, silt, and gravel. These soils are fairly permeable, and allow for rapid recharge to the bedrock aquifers.

Geology--

Bedrock underlying the plant site consists of limestones and dolomites which strike east-northeast and exhibit a dip of 30° to the southeast (Ontelaunee Formation (Dolomite) = 900 ft thick; underlying Annville Formation (high calcium limestone) = 1,500 ft thick north of the plant).

Hydrology--

The site lies adjacent to Tulpehocken Creek (37 miles upstream from its confluence with the Schuylkill River, which in turn flows to Delaware Bay). The drainage basin of Tulpehocken Creek covers 211 mi^2 and is 33.5 miles long. The average and minimum flows at the confluence of Schuylkill River are 58 cfs and 56 cfs, respectively. The average annual flow for the creek is approximately 200 cfs and the maximum flood flow was 9,890 cfs (on December 7, 1953). The creek flows east-northeast (following the strike of the carbonate bedrock).

Ground water beneath the site is potable and is used by local residents and farmers. There are some artesian wells near the site, but the static water level in most wells lies near the ground water table. The site lies close to a ground water divide in a system of limestone aquifers underlying the Lebanon Valley.

Releases

Types/Causes of Releases--

Improper waste disposal in an unlined surface impoundment (lagoon) caused releases to ground water underlying the site, soils onsite, and a nearby stream (Tulpehocken Creek).

Mechanisms for Detection--

In July 1964, Whitmoyer Laboratories, Inc. became a subsidiary of Rohm & Haas Company. Extensive arsenic contamination of the soils, ground water, and a nearby stream became apparent to Rohm & Haas Company officials during an inspection of the facility.

Extent of Contamination--

Extensive ground water, soils, and surface water contamination exists in the site area. Hazardous constituents primarily include organically-bound arsenic compounds, calcium arsenate, and calcium arsenite.

Remedial Actions

Response Actions--

Onsite treatment and disposal practices were discontinued in December 1964. Sludge was removed from the lagoon. Contaminated soils underlying the lagoon were also removed. The contaminated soil and sludge materials were deposited in an impervious concrete storage bin, which was filled to capacity and then covered.

Four recovery wells were used to purge ground water containing arsenic compounds. The contaminated ground water was treated by adding two-parts $Fe_2(SO_4)_3$ to one-part arsenic and adjusting the pH to neutral conditions (by adding lime). Recovered water was handled in alternating batch mixing tanks on a continuous feed treatment schedule and sent to the lagoons to dissipate via slow percolation to the subsoil.

The plant reopened in the Spring of 1965 on a no-discharge basis. Treated wastes were trucked to a New Jersey holding area awaiting ocean dumping. In 1966, additional wells were installed. Production wells formed cones of depression east of the plant to stop migration of ground water. Production rate is partially dependent on the purging rate. From 1968 to early 1971, the purged water was discharged directly to Tulpehocken Creek.

It was decided that it would be too expensive to dredge Tulpehocken Creek, and the constituent levels are declining through dilution. Whitmoyer Laboratories currently supplies bottled water to area residents whose wells remain affected.

Success/Failure of Remediation--

The first phase of remedial action cleanup and recovery involved the removal of sludge and contaminated soils. The manufacturing processes were halted until a process could be developed to remove arsenic from the wastewater, thereby eliminating the possibility of new arsenic compounds being added to the soils, and subsequently to the ground and surface water.

The next phase, which involved removal of the arsenic constituents from the ground water, was also successful. The recycling and treatment of the purged water did reduce the level of arsenic in the ground water, and succeeded in controlling its movement.

Little has been done to remove the hazardous constituents from the sediments and surface water of Tulpehocken Creek, because of the costs involved in dredging miles of creek bottoms and banks. Through dilution, the arsenic levels in the creek water have been brought within the limits set by the U.S. Department of Health, and monitoring has shown that the levels continue to decline.

Finally, routine monitoring of the site is being performed to ensure that the arsenic levels do not increase, either through the release of arsenic from bottom muds, or via spills from the plant.

Reference: EPA, 1981.

ENTERPRISE AVENUE - PHILADELPHIA, PENNSYLVANIA

Facility Description

The Enterprise Avenue landfill site occupies approximately 57 acres, 40 acres of which have been filled. The site is located in an industrial area. The closest residential population is located approximately 2 miles northwest of the site.

The Enterprise Avenue site was used by the city of Philadelphia for the disposal of incineration residues, fly ash, and debris. Drums containing various industrial and chemical wastes were illegally buried at the site by several waste handling firms.

Site Characteristics

Topography--

The site is relatively flat. Vegetation is present over most of the site area.

Geology/Soils--

Soils overlying the site consist of a low permeability, silty clay layer ranging in thickness from 5 ft on the western boundary to 25 ft along the eastern perimeter. Underlying the silty-clay horizon is a gravelly sand.

Hydrology--

Two ground water aquifers underly the site. The uppermost water-bearing zone is a perched water table and is encountered above the silty clay layer. Portions of the shallow aquifer zone are mounded into the bottom of the fill material. The deeper, confined aquifer is found in the sands and gravels that lie beneath the silty clay. The ground water present in these water-bearing zones is not used in the general area of the site. However, the deeper aquifer may recharge sources of ground water for portions of southern New Jersey. The observed flow in the deep aquifer is east towards the Delaware River.

Releases

Types/Causes of Releases--

Illegal burying of drums containing industrial and chemical wastes at the site resulted in contamination of soils and ground water onsite. Hazardous constituents leaked from the drums to the surrounding soils and into the underlying ground water. Infiltration of precipitation caused leaching of hazardous constituents and further transport of constituents to soils and ground water.

Mechanisms for Detection--

In response to reports of unauthorized dumping of industrial wastes, the Philadelphia Water Department (PWD) conducted exploratory excavations during January 1979 to investigate these reports. Initially, approximately 1,700 55-gallon drums were uncovered. Most of the drums were broken and fragmented. Subsequently, sampling and analysis activities were conducted to determine the extent of contamination.

Extent of Contamination--

The drums which were illegally disposed onsite contained industrial wastes and chemical wastes such as paint sludges, solvents, oils, resins, metal finishing wastes, and solid inorganic wastes. The total number of drums disposed of at the site was estimated to be between 5,000 and 15,000 drums. Approximately 532,000 yd^3 of material were landfilled.

The site lies on the 100-year floodplain of the Delaware River. The analysis of surface water samples in the site area did not indicate any quantifiable pattern of contamination contributed by the landfill.

The shallow water-bearing zone within the site boundary was found to be contaminated. The contamination in the shallow aquifer was localized and primarily organic in nature. The underlying deep aquifer was essentially unaffected by the wastes disposed at the site. The presence of the silty clay layer under the site serves as a barrier to vertical movement of water from the shallow to the deep aquifer.

Remedial Actions

Response--

The initial response (Phase I) at the site was funded by the Philadelphia Water Department. Drums and drum fragments were removed and disposed offsite. Contaminated soils were excavated and stockpiled into two piles; one pile for offsite disposal or treatment, and the other pile for backfilling onsite. The soils were separated on the basis of analytical results. Indicator limits were set for TOX (25 ppm), volatile organics (12 to 15 ppb), and metals; those soils which measured above the indicator limits were placed in the pile for offsite disposal or treatment, and those which were below the limits were placed in the pile for backfilling onsite.

After 32,000 yd^3 of soils had been excavated, the Philadelphia Water Department ran out of funds. At this time, 17,000 yd^3 of the excavated soils were disposed offsite and the other 15,000 yd^3 remained onsite.

Remedial actions continued at the site when Superfund money became available. Stockpiled soils were resampled and analyzed by the EPA. Excavation of the contaminated soils was continued. The contaminated soils were disposed of offsite at an EPA-approved facility. The remainder of the soils were backfilled onsite. The site was then graded with a layer of low permeability clay overlain by sandy soil and topsoil. Finally, the topsoil was reseeded and revegetated.

Success/Failure of Remediation--

Monitoring data collected has shown that the remedial action has been effective in removing the contaminated soil material. It is expected that the infiltration of precipitation to the ground water aquifer will be minimal. Although measures were not taken to clean up contaminated ground water and/or control its migration, site investigations have shown that it will probably not present a problem to public water supply. Hazardous constituents in the ground water are expected to volatilize, degrade chemically or biologically, or be diluted over time.

References: Hernandez, 1985; Roy F. Weston, Inc., 1985; Versar, Inc, 1985.

FRONTENAC SITE - FRONTENAC, MISSOURI

Facility Description

During the 1970s, the Frontenac site was used as a storage area for waste oils and chemical wastes hauled by a waste oil company. The illegal storage and transfer of 2,3,7,8-TCDD-contaminated wastes at the site resulted in contamination of the soils onsite and an adjacent creek (Deer Creek). Through improper waste handling and disposal practices, oils containing chemical contaminants were allowed to leak from storage vaults onto the surrounding soils and drain into Deer Creek.

Site Characteristics

Climate--

The annual average precipitation (1944 to 1983) in the site area is 36.41 in. Average daily mean temperatures (1951 to 1980) range from 32.3°F (winter) to 76.9°F (summer) with an annual average daily mean temperature of 55.4°F. The annual average wind speed (1949 to 1983) is 4.3 m/sec.

Topography--

The Frontenac site lies at an elevation of approximately 525 ft above mean sea level (MSL). The site is relatively flat, but slopes slightly southeast toward Deer Creek. Onsite surface water drains toward the southeast corner of the site into the adjacent Deer Creek by way of a drainage swale.

Soils--

The soils at the site are mostly floodplain sediments consisting of stratified sands, silts, and clays. Gravel, cinders, and concrete fragments are present near the site surface.

Geology--

The Frontenac site lies within the southeastern corner of the Dissected Till Plains geologic subprovince of Missouri. Bedrock formations that underlie the site are chiefly Mississippian-aged limestones that become shaley toward the basal part of the Mississippian system.

Hydrology--

The Frontenac site lies adjacent to and on the 100-year floodplain of Deer Creek, which flows approximately 7.5 miles to the southeast where it empties into the River des Peres, a tributary of the Mississippi River.

Deer Creek is a major source of flooding within the city of Frontenac. Flash floods which occur along this stream are generally caused by localized, intense thunderstorm activity which is typical of the northwest. The size of the Deer Creek watershed in the area of the site is 5.7 square miles. The peak discharge at this location for the 10-, 50-, 100-, and 500-year floods are 3,500, 5,700, 6,800, and 9,500 cfs (cubic feet per second), respectively.

Ground water in the area of the Frontenac site occurs within limestone bedrock formations. Water may be obtained in limited quantities from wells penetrating the limestone at depths of 150 to 200 ft. This water occurs in fractures and dissolution channels, with highly variable yields. Most of these wells yield a maximum of 10 to 15 gpm (gallons per minute); below this depth the water becomes very saline and is generally unfit for use. Drinking water in the site area is obtained from the metropolitan St. Louis area public water supply which obtains water from the Missouri and Mississippi Rivers.

Releases

Types/Causes of Releases--

The owner/operator of the storage site illegally accepted chemical wastes containing dioxin (2,3,7,8-TCDD) for storage at the Frontenac site and subsequent disposal at other sites. Improper handling of these chemical wastes caused hazardous substances (predominantly dioxin-contaminated wastes) to be released (through spillage, leakage, and runoff) to onsite surface soils and an adjacent creek (Deer Creek).

Mechanisms for Detection--

A safety inspection was conducted at the site in 1976 by Industrial Testing Laboratories and the Frontenac City Fire Chief. The ground around the tanks was found to be so saturated with spilled material that a continuous stream of seepage could be observed to be entering Deer Creek.

An additional site inspection, which was conducted by the U.S. EPA Region VII Emergency Response Section in April 1977, concluded that the Frontenac site did not have the required Spill Prevention and Countermeasure (SPCC) Plan and thus, was in violation of 40 CFR 112.3(a),(d).

During an EPA investigation of dioxin contamination at several horse arena sites in Missouri, it was learned that the waste oil company may have been a responsible party. Subsequent sampling and analysis performed at the site in 1983 revealed the presence of 2,3,7,8-TCDD (dioxin).

Extent of Contamination--

Sampling and analysis efforts conducted at the Frontenac site have demonstrated that 2,3,7,8-TCDD exists onsite, within at least the uppermost foot of soil. The soil contamination extends over most, if not all, of the area where the storage tanks were formerly located. Additional 2,3,7,8-TCDD contamination has been confirmed in sediment samples collected from a portion of Deer Creek (200 ft of the 300 ft reach of Deer Creek adjacent to the site) at a depth interval of 0 to 2 in. 2,3,7,8-TCDD has not been detected in samples taken upstream and downstream of the Frontenac site.

Remedial Actions

Response--

During the period from 1977 to 1979, the sludge and waste materials were removed from the storage tanks and the tanks were removed from the site. The dioxin-contaminated wastes were sent to an EPA-approved incineration facility in Louisiana. The remaining wastes were transferred into 55-gallon drums and buried in an approved hazardous waste landfill in Missouri. Following the removal of the storage tanks, the area where the tanks were formerly located was covered by the owner with a layer of crushed gravel.

In April 1984, the site was listed as a CERCLA Superfund site. During June 1984, interim remedial measures were undertaken at the Frontenac site. The site was paved with asphaltic concrete over a newly placed gravel subgrade. A toe-trench was dug near the creek and filled with rip-rap to prevent erosion of the stream bank. In order to restrict access to the paved area, a 1/2-in. wire cable was strung on 5 ft steel stakes spaced at 20 ft intervals around the east, north, and west perimeters of the site.

Success/Failure of Remediation--

The remedial actions taken at the Frontenac site are considered interim measures only. Although sampling and analysis has not been performed since the installation of the interim measures, periodic site inspections have shown that these measures have been effective in preventing erosion and infiltration of precipitation. Final measures are being considered at this time.

Reference: GCA, 1984c.

CRYSTAL CHEMICAL - HOUSTON, TEXAS

Facility Description

The Crystal Chemical site is an abandoned herbicide manufacturing plant. During 1956 through 1981, the plant produced arsenic; phenolic; and amine-based herbicides. Wastes from the manufacturing process were placed in four onsite evaporation ponds. Originally, there was no leak detection or monitoring system present at the site. The site is currently on the list of Superfund sites and is in litigation (i.e., the EPA is currently negotiating with the responsible parties for site cleanup).

Site Characteristics

Soils--

Soils underlying the site consist of silty clays in the upper 10 to 18 feet. Sandy silts and clays are found below this depth. Permeability of the silty fine sands has been estimated to range from 10^{-3} to 10^{-4} cm/sec.

Geology--

The site is situated on the outcrop of the Beaumont Formation of Pleistocene Age. The Beaumont Formation, which is found in the site area at depths of 0 to 150 ft consists of backswamp, point bar, natural levee, and stream channel deposits containing clay, silt, and sand. Underlying this layer to a depth of 650 ft are the Montgomery, Bentley, and Wilis Formations which consist of clays, silt, and sand with minor amounts of siliceous gravel.

Hydrology--

Surface runoff from the site flows to a flood control channel (western boundary of the site) and drains to the Brays Bayou (approximately 1-mile from the site). Since elevated levels of arsenic were detected in the adjaent flood control channel, it is suspected that Brays Bayou may have become contaminated following flooding.

Two water-bearing zones underlie the site; both are contaminated. The depth to the first sand water-bearing zone is approximately 15 ft below the surface. The second sand water-bearing zone is located at a depth of 35 ft below the surface. Although there are interconnections between the water-bearing zones, hazardous constituents have not been detected in the major water-bearing zone (i.e., used for Houston water supply) located approximately 200 ft below the surface.

Releases

Types/Causes of Releases--

Raw and finished containerized materials were stored on the ground in the open. Materials spilled occasionally and leached into the surface soils. Additionally, arsenic trioxide was received in bulk by rail and poor containment practices were used during unloading.

Periodic flooding occurred at the site. Dikes were used in an attempt to convey surface water runoff from the process operation area to an area in close proximity to the manufacturing facilities. In 1976, a significant flood occurred which overflowed the dikes releasing hazardous constituents into an adjacent flood control channel and possibly into Brays Bayou.

In addition to surface water and ground water relases, airborne arsenic was released to offsite areas during mechanical aeration of the waste evaporation ponds.

Mechanisms for Detection--

In 1971, the Texas Water Quality Board (now the Texas Department of Water Resources) noted during an inspection that there was a potential for both onsite and offsite contamination. During subsequent routine inspections (late 1970's), Crystal Chemical Company was cited for several license violations including spills, poor housekeeping, worker safety violations, and discharge of contaminated wastewater and stormwater runoff. In 1977, the company was cited and fined by the Texas Water Quality Board for unauthorized discharge of arsenic contaminated wastewater.

Complaints from residents of nearby apartment complexes and businesses of discolored water resulted in further investigations by the Texas Water Quality Control Board. Arsenic contamination was discovered in air conditioning filters in residences immediately downwind of the waste evaporation ponds. It was determined that the Crystal Chemical site was the source of contamination.

Extent of Contamination--

Phenol-based and arsenic-based herbicide manufacturing wastes were disposed at the site, resulting in arsenic and phenol contamination. An estimated 89,000 yd^3 of soils onsite are contaminated with 100 mg/kg of arsenic. Ground water under the entire site is contaminated to the 35 ft sand layer. The contaminated ground water plume has migrated 150 ft offsite, extending approximately 200 ft to the north in a somewhat oval-shaped pattern. Although sampling and analysis activities have not been conducted in Brays Bayou, it is likely that surface water contamination from surface runoff exists in Brays Bayou.

Remedial Actions

Response--

Contaminated surface water (from the flooding incident) was removed. Equipment and buildings were removed (i.e., site was leveled). Former waste pits (lagoons) were backfilled and the entire site was capped with a 1 to 2 in. clay layer overlain by a plastic top to serve as a temporary cap.

Periodic sampling and analysis has been performed since 1983. Currently, there are 13 monitoring wells in operation.

Success/Failure of Remediation--

Only interim measures (emergency removal actions) have been taken to date. The RI/FS has been completed (as of June 1984) and reviewed at EPA Headquarters. Appropriate remedial actions currently being considered by the EPA include: capping, and the construction of a slurry wall.

References: Gilrein, 1985; Versar, Inc., 1985; D'Appolonia Waste Management Services, et. al., 1984.

SILRESIM - LOWELL, MASSACHUSETTS

Facility Description

During the period from 1971 to 1978, the site was used for the operation of a chemical reclamation facility which was designed and licensed for the ultimate disposal or recycling of chemical wastes. Solvents were recovered through a distillation process (evaporation/concentration system); and wastes were stored and/or disposed onsite. In 1978, the company's license was revoked and the site was abandoned leaving approximately 1-million gallons of hazardous wastes stored in drums and bulk storage tanks. The site is currently under Superfund status.

Site Characteristics

Topography--

The vertical relief in the site area is approximately 5 ft.

Soils--

Soils in the site consist of fine- to medium-grained sands, and are moderately well drained. The sand-silt strata is approximately 100 ft thick.

Geology--

The site is located on a glacial outwash plain. The depth to bedrock is approximately 5 ft. The bedrock material is permeable.

Hydrology--

The ground water table is parallel to the site's surface topography. The distance to the shallow aquifer is less than 5 ft. Maximum ground water contamination occurs at depths of 20 ft or less. Ground water movement is to the north at a rate of approximately 16 ft/yr.

River Meadow Brook is located approximately 300 ft west of the site. Low levels of contamination were found in the surface water.

Releases

Types/Causes of Releases--

Surface runoff caused hazardous constituents to be transported to soils on the site and to River Meadow Brook (approximately 300 ft west of the site). Leachate from the contaminated soils permeated the bedrock and contaminated the shallow ground water aquifer.

Mechanisms for Detection--

In 1974, the company experienced financial problems and began to be unselective about the types of wastes it would accept. Permit violations were discovered during a routine MWPC inspection conducted in 1975. Additional license violations were discovered in 1977. The company's license was revoked in 1978, after continued violations. Operations ceased and the site was abandoned. Site investigations and monitoring activities have been ongoing since the original discovery of contamination.

Extent of Contamination--

Chemical reclamation wastes from over 35 different chemical processes were disposed at the site, including acids, alkalis, solvents, pesticides, and plating wastes. Hazardous constituents found at the site include: volatile organic compounds, PCBs, pesticides, and some metals.

Contamination has been found in air, surface water (River Meadow Brook), surface runoff, soils, and ground water. Maximum soil contamination occurs at a depth of 10 ft or less below the surface. High levels of hazardous constituents have been found in the shallow aquifer. The extent of the hazardous constituent plume is approximately 50 ft deep, 1,000 ft north/south, and 800 ft east/west.

Remedial Actions

Response--

In March 1978, berms were constructed and absorbent fill material was placed in the disposal trenches (surface impoundments) to reduce the spread of surface contamination.

In 1981, drums and chemicals in bulk storage tanks were removed, with the exception of approximately 78,000 gallons of PCB-contaminated solvent waste (in bulk storage).

In 1982, the buildings and most of the containers were removed (with the exception of a few underground tanks). Approximately 6,000 gallons of volatile organic compounds are reportedly beneath the site. It is estimated that 8 percent by weight are in the ground water, and 92 percent by weight are in the soil.

During 1983 and 1984, the site was capped using a 14 in. layer of compacted clay with gas-venting system to minimize surface water and rainwater infiltration.

Periodic sampling and analysis has been performed since 1976, using eight monitoring wells now present on the site. A new evaluation is scheduled for 1985 because the removal of buildings, etc., is believed to have changed the ground water table.

Success/Failure of Remediation--

Remedial response actions taken to date are considered to be interim measures. The interim measures have slowed the migration of hazardous constituents, but not significantly. The RI/FS is currently being prepared (Perkins-Jordan prepared a report similar to an RI/FS in 1979). Wells continue to be monitored to define the rate and nature of migration.

References: Ciiello, 1985; Versar, Inc., 1985.

SECTION 5

RECOMMENDATIONS ON HOW TO SELECT AND IMPLEMENT CORRECTIVE MEASURES

INTRODUCTION

An overview of corrective measures for soil releases has been presented in Section 3. The proven, imminent and emerging technologies, summarized in Table 3-1, are used to treat, destroy or dispose of contaminated soil in order to eliminate or mitigate a threat to human health and the environment.

There are many technologies presently available that are capable of treating or disposing of contamination within the soil horizon. These range from such methods as excavation followed by capping or landfilling to newer technologies such as incineration, which can typically render the hazardous constituents non-hazardous. An important consideration in selecting corrective measures is to examine available technologies with respect to types of hazardous constituents prevalent at the site and site characteristics. The most appropriate corrective action can then be selected and recommended. As can be seen from summary Table 3-2, certain hazardous constituent types and technologies are amenable to each other while others are not. Therefore, the appropriateness of certain corrective measures must first be determined for specific constituent types. Following initial screening of appropriate technologies, the site characteristics must also be considered in selecting the final corrective measure. For example, contamination present at great depths may not be amenable to in situ methods of treatment. Capping and landfilling may also be inappropriate in such circumstances if a high ground water table is present or in conjunction with highly permeable soils. These measures would not likely provide adequate long term protection to human health and the environment. Table 5-1 is a summary of pertinent issues discussed in this section.

TABLE 5-1. PERTINENT ISSUES FOR SELECTION AND IMPLEMENTATION OF CORRECTIVE MEASURES

Site Investigation	
Characterize extent and type of hazardous constituent release	• Waste types and amounts released • Extent of migration • Chemical and physical properties of the waste • Fate and transport of chemicals to receptors
Soil Conditions	• Soil type • Permeability • Porosity • Cation exchange capacity • Redox potential • Organic carbon content • Engineering parameters such as plasticity, atterberg limits and moisture content
Site Location	• Proximity of local population • Proximity of municipal and private ground water sources • Locations of drainage areas and surface water bodies • Local climate including precipitation, temperature and wind data
Hydrogeology	• Overburden characteristics • Bedrock characteristics including extent of weathering, fracturing, jointing and foliation • Depth to ground water • Location of uppermost and useable aquifers • Hydraulic gradients • Hydraulic conductivity • Ground water velocity
Screening of Measures	
Technical Considerations	
Performance	• Effectiveness of measure to perform intended functions, including demonstrated performance • Overall time period a measure will adequately perform (useful life)

(continued)

TABLE 5-1 (continued)

Reliability	• Ability to protect human health and environment • Operation and maintenance characteristics of the corrective measure
Implementability	• Ease of installation under given site conditions • Ease of installation under conditions external to the site • Time required to implement and attain desired results
Safety	• Short term safety issues concerning workers and local populations • Long term safety issues concerning onsite employees and local populations
Public Health Considerations	• Site contaminant, extent and nature • Fate, transport and exposure of contaminants • Anticipated dose, and frequency of exposure by receptors • Toxicity of contaminant
Environmental Considerations	• Identify impacted environments • Ensure corrective measures address environmental threat posed • Assess possible future impacts from corrective measure
Institutional Considerations	• Compliance with Federal, State and local regulations • Identify possible non-compliance areas where variances may be needed
Cost Considerations	• Detailed cost analysis including direct and indirect capital costs • Present worth analysis • Operation and maintenance costs • Determine most cost effective measure
Selection	• Ensure all aspects of site investigation and screening are adequate • Select measure that focuses on and will effectively mitigate the posed endangerment

(continued)

TABLE 5-1 (continued)

Recommendation	• Permit writer must ensure that the proposed corrective measure is adequate and may recommend more applicable measures if necessary
Conceptual Design	• Detailed corrective measure design • Detailed drawings and specifications • Work schedules • Process descriptions
Implementation	• Unit or process installation • Field inspections • Quality control on construction
Monitoring	• Monitor unsaturated zone and ground water to determine success or failure of corrective measure

Section Objectives

This section of the report will develop for the permit writer an approach for selecting and implementing a corrective measure. It will provide a logical sequence of decision making processes and activities to guide the permit writer in reviewing proposed corrective measures for releases to soil. This progression involves the following important considerations:

- adequate site investigation,
- screening,
- selection,
- recommendations,
- conceptual design,
- implementation, and
- monitoring.

Case studies presented in Section 4 and corrective measures described in Section 3 will also be used to illustrate remedial actions taken at various SWMUs and other facilities for release to soils. These will be used to demonstrate the success or failure of the remedial measure taken, and to analyze why these successes and failures occurred. The interaction between technology, hazardous constituent types, and site characteristics will be discussed in terms of how the particular remedial action was chosen and why expected results were or were not realized. Finally, this section will provide the permit writer with a summary of the important issues and considerations that are necessary in the selection process.

IMPORTANT CONSIDERATIONS IN SELECTING CORRECTIVE MEASURES FOR RELEASES TO SOILS

Once a release has been documented, or suspected to have occurred as evidenced by a preliminary site assessment, it may be necessary to implement a corrective measure. The correct selection of an appropriate corrective action requires that the applicant follow a logical progression of decision making processes presented previously, to be able to select the corrective measure that is the most technically sound, that will provide the most protection to human health, the environment, and that will comply with various environmental laws, and that is cost effective. This progression should also be performed by the permit writer to be assured that the applicant has considered all available corrective measures and has selected the most appropriate one.

Site Investigation

Once a preliminary site assessment indicates that a release has occurred and that the release is a potential hazard to public health and the environment, a thorough site investigation is necessary to determine specific site characteristics. The permit writer must examine the available data submitted by the applicant and decide upon the adequacy of the site investigation with respect to selecting an appropriate corrective measure for remediation. The permit writer should identify any data gaps that may affect the final selected action. The following must be properly characterized:

- Hazardous constituent characteristics (migration potential),
- Extent of contamination (potential receptors),
- Soil Considerations,
- Site Location,
- Geology, and
- Hydrology.

These parameters will greatly influence the selection of an appropriate corrective measure and its final engineering design. Many of the characteristics needed to be identified may already be available through previous site investigations which should be used as a base-line for any further investigation.

Characterization of Extent and Type of Hazardous Constituent Release--

During the site investigation the extent and type of hazardous constituent(s) that was released must be determined. The type of hazardous constituent that is released will influence the selection, design and implementation of a corrective measure. As shown in Section 3 of this report, certain technologies may only pertain to certain types of soil contamination. For example, biodegradation, either in situ or above grade, is only applicable to organic constituents.

The chemical and physical properties of a chemical type must also be known in order to determine appropriate remedial actions. Parameters such as water solubility, adsorbability onto soil particles, volatility and biodegradability are important in the final selection of a corrective measure. If possible, the amount of hazardous constituents released should be quantified to assess the magnitude of the spill or release. Knowledge about the toxicity of the hazardous constituent and about the fate and transport of the chemicals to potential environmental receptors is also critical in deciding if the release poses a potential threat to human health and the environment and if immediate corrective actions must be taken. If highly toxic materials have been released, and environmental receptors identified, then immediate responses may be warranted to mitigate an impending risk to human health and the environment.

The soils at the site must be adequately defined and the hazardous constituent levels in the soil horizon must be properly characterized. This normally can be accomplished through the excavation of tests pits or from soil borings if contamination is expected to be at substantial depths. Shallow surface sampling can easily be performed to determine the extent of surficial contamination. The sampling approach should characterize both the lateral and vertical extent of contamination. This is needed to determine if the contamination exists below the mean seasonal high water table, and to estimate the amount of soils that will require excavation and/or treatment.

Soil Conditions--

The determination of soil characteristics, soil types, permeability and porosity is needed to assess the potential of hazardous constituent migration from the soil into ground water and resulting offsite migration to possible receptors.

Several chemical parameters also affect hazardous constituent migration from soil. Soil pH greatly effects the mobility of many metals, as well cation exchange capacity. High cation exchange capacities, for example, tend to immobilize metals within the soil. The redox potential (Eh) of a soil also effects the oxidation state and resulting stability of both organics and metals in the soil.

Other parameters such as total organic carbon content, plasticity limits, Atterberg limits, and moisture content also influence hazardous constituent migration and should, therefore, also be examined. Such parameters will influence the appropriateness of the selected corrective measure as well as the engineering design and methods of implementation.

Site Location--

The site location is very important in the final selection of a corrective measure. Factors such as proximity to local populations can effect the corrective action selected and its implementation. For example, if there are nearby populations and there is a release of organics to soils, biological treatment may be considered as a viable treatment option. However, these populations may be impacted by persistent odors generated throughout the treatment period therefore eliminating this measure from further consideration.

The proximity of the contaminated soil to municipal or private ground water supplies is also a major concern. Options for clean up must adequately protect against the contamination reaching the ground water and migrating offsite, thereby causing a possible human health concern. The proximity of surface water bodies, such as lakes, rivers and streams, must also be assessed. Surface water run-off from the contaminated soil must not be allowed to impact nearby water bodies. Care must also be taken not to allow a release, or effects from corrective action implementation, to impact local ecological systems.

Additionally, information on the local climate is an important part of the selection process. Temperature data including monthly, seasonal and yearly means along with depth of frost, if applicable, are crucial parameters. Such knowledge permits the proper scheduling and implementation of treatment processes, which are influenced by ambient temperature. Such processes as biological treatment are impaired by cold temperatures and, therefore, may only be viable during warm seasons. The depth of frost is very important in designing an impermeable cap or landfill. Adequate coverage over the impermeable synthetic material or clay layer is necessary. Freeze-thaw cycles can cause cracking in clays and decrease the integrity of synthetic liners at a rapid rate. This in turn decreases the reliability, performance and useful life of the unit.

Monthly, seasonal, and annual precipitation values are important in determining hazardous constituent migration rates through soils. This must also be known to determine the water balance of the site. Corrective measure implementation is also affected by seasonal precipitation values. This is especially true if the measure involves extensive excavation at great depths or if contamination is close to water table elevations. Determination of these data are important in scheduling construction activities.

Wind direction and speed also affect corrective measures that involve large amounts of excavation. Local populations may be subjected to fugutive dust emissions, unless effective dust suppression methods are used. Odors may also be carried to nearby populations through prevailing winds, thereby creating health hazard.

Hydrogeology--

The hydrogeology of a site is one of the most important factors concerning the selection of a corrective measure. The overburden and bedrock at the site in the area of the release must be adequately characterized to assess the pathways of migration. Parameters such as sand and gravel overburden, highly weathered bedrock, fracturing, jointing and existence of foliation can greatly increase the hazardous constituent migration rate. All of these parameters must be well defined through such methods as field mapping and subsurface borings. Sites with fractured or highly jointed bedrock may not be amenable to on-site storage because hazardous constituent migration may be quite rapid. This type of site condition may require removal or ultimate treatment in order to mitigate potential hazardous constituent migration.

Such hydrologic parameters as depth to water table during wet and dry seasons and definition of the uppermost and useable aquifers must be considered when deciding on a corrective measure, its engineering design and implementation. Depth to ground water is important in determining if soils can be easily excavated or if capping or landfilling are viable corrective measures for implementation at the site in question.

Other parameters such as hydraulic gradient, hydraulic conductivity, porosity and ground water velocity should be considered in assessing hazardous constituent migration from soil into ground water. Furthermore, both the lateral and the vertical extent of contamination must be characterized to select an appropriate ground water interception and treatment method.

Screening

Upon adequate completion of the site investigation, the next step in selecting a corrective measure involves the development and screening of possible corrective measures. The initial step in the screening process is the development of general response objectives to identify the goals and extent of the corrective measure to be used. The site investigation should identify the possible receptors. Corrective measures that will mitigate the threat posed to these receptors can then be formulated. For example, if exposure to the hazardous constituent release is determined to be by direct contact of onsite workers or trespassers, then capping and access restriction may be adequate. However, if the release is found to be highly toxic with the possibility of migration into ground water, a measure that will treat the hazardous constituents to acceptable levels, or excavation and removal may be required.

All applicable technologies should be gathered for consideration. These should then be screened to eliminate those that are clearly not as applicable as others using the following criteria:

- Technical,
- Public Health,
- Environmental,
- Institutional, and
- Cost.

Technical Considerations--

A primary concern when screening proposed measures is to identify those that are technically feasible under given site conditions. Both proven and imminent technologies should be investigated in some detail in terms of engineering design and overall implementability. Some of the technical issues that are addressed in a CERCLA feasibility study can also be considered when assessing corrective measures for a hazardous constituent release to soil at a RCRA facility (i.e. SWMU). The following discusses some of the technical issues that a permit writer should consider when reviewing an application for corrective measures implementation. The following technical considerations will be discussed:

- Performance,
- Reliability,
- Implementability, and
- Safety.

Performance--It is important to be able to determine how well a corrective measure will perform once implemented. In order to do this the effectiveness of the measure or its ability to perform its intended functions must be analyzed. Therefore, it must be demonstrated that the remedial action selected whether it be removal, containment, destruction or treatment, will properly perform and be effective as a corrective measure in eliminating present and future human health and environmental impact.

Another aspect of performance is the useful life of the proposed measures. Each measure should be examined to determine the length of time it will be able to adequately perform. The useful life of the remedial action must, therefore be determined to assess the overall performance of the measure.

Reliability--Each remedial measure must be assessed in terms of its reliability in protecting human health and the environment considering both hazardous constituents present and site conditions. Therefore, the demonstrated performance of a corrective measure should be determined. This assessment can consist of evaluating the performance of the technology at similar sites or by using pilot scale studies to evaluate actual performance.

The amount of operation and maintenance that is required by a corrective measure also effects its reliability. A measure may be less reliable if it involves many complicated operation and maintenance activities, whereas a measure with simple and less frequent operating and maintenance activities can be considered more reliable. Treatment technologies, for example, may render contaminated soil non-hazardous, thereby enabling it to be disposed of; as per applicable regulations.

Implementability--Each proposed measure must be evaluated in terms of its ease of installation at the site in question. In order for a measure to be selected for remediation it must be readily implemented in a reasonable period of time. It must be ascertained that both site conditions and conditions external to the site will be amenable to the proposed corrective measure.

Time to implement and the amount of time to see desired results must be investigated. It is important that a corrective measure not take too long to implement since contamination may migrate from the soil into the ground water. Also, measures that quickly mitigate the threat posed by a release are more desirable than those that take a longer period of time.

Safety--The final technical evaluation of a corrective measure is safety. The evaluation should include the safety provided to onsite workers and offsite local and distant populations both during and after final implementation. Measures that expose workers and populations to potentially hazardous conditions should not be as highly regarded as those that minimize these conditions. Corrective measures should be designed such that they minimize risk during the construction/implementation phase and should be evaluated regarding the ability of the final design to provide continued safety.

Public Health Considerations--

For a corrective measure to be implemented at a SWMU it must provide protection to public health, including both onsite workers and offsite residents. The key components of such an evaluation include:

- extent and nature of site contamination,
- fate and transport of hazardous constituents from the site,
- exposure of local and distant populations(both human and nonhuman) to the hazardous constituents,
- projected dose of the contamination to environmental receptors,
- anticipated frequency of hazardous constituents exposure to environmental receptors,
- toxicity and health hazard of the hazardous constituents, and
- risk assessment with exposure to the hazardous constituents.

The initial step in considering human health risks is to evaluate all pertinent data from the site investigation. Factors such as constituent types, quantities, spilled, and extent of contamination are critical issues to be addressed. The population(s) at risks should also be determined.

An important part of choosing a corrective measure is to ascertain the potential for hazardous constituent migration and the potential exposure routes. Mechanisms by which populations will be exposed to the contamination greatly influences the final decision on corrective measures and their design. If a release to soil has the potential to migrate into a useable aquifer, then care must be taken to ensure that the measure chosen will either treat the contaminated soil to appropriate levels or remove it so the public will not be affected through contaminated drinking water.

Air quality standards and water quality standards must not be violated due to the release. If standards have been exceeded due to a release, then any corrective measures implemented should ensure that required levels be attained.

Environmental Considerations--

The next step in the screening process is to make an environmental assessment concerning impacts to the environment. Again, data from the site investigation is a primary source of information. It must be ensured that the corrective measure achieve adequate protection and/or improvement to the environment.

Each proposed measure must be analyzed to determine the extent of environmental benefit that will be attained through its implementation. It must be determined what part of the environment is, or potentially will be, impacted from the release. The following consist of environments that may be impacted:

- Ground water,
- Surface water,
- Soils,
- Air,
- Sole source aquifers,
- Wetlands,
- Flood plains,
- Coastal zone,
- Critical habitats,
- Prime agricultural lands,
- Federal parklands,
- National forest,
- Wildlife sanctuaries/refuges, and
- Habitat productivity.

Another area of environmental concern is the affect on various human resources such as:

- Commercial,
- Residential,
- Recreational,
- Aesthetic, and
- Cultural.

Corrective measures must try to minimize the impact to these resources. For example, loss of water supplies and unpleasant odors can reduce local property values in a residential community. Migration of contamination to a stream or lake can impact the population of the surface water body and result in a loss of recreational area.

Another area that must be explored in the environmental assessment is the environment which has been affected and whether or not it can be returned to its previous condition. Additionally, potential impacts on the environment as a result of corrective measure implementation, must also be assessed.

Institutional Considerations--

Each of the proposed corrective measures that is being screened should consider various institutional concerns. This involves assuring that the corrective measure used for remediation is in compliance with existing federal (EPA), state and local laws. Some of the federal regulations that should be considered consist of:

- Ground Water Protection Strategy,
- The Wild and Scenic Rivers Act,
- The National Historic Preservation Act,
- The Endangered Species Act,
- Archeological and historic preservation,
- The Coastal Zone Management Act,
- Fish and Wildlife Coordination Act,
- Flood Disaster Protection Act,
- Uniform Relocation Assistance and Real Property Acquisition Policies Act, and
- Executive Order 12372, 11988 and 11990.

State regulations concerning flood plains, wetlands, surface water and development of new aquifers should also be considered when screening corrective measures.

Along with federal and state regulations, local laws pertaining to erosion control, zoning, building permits, rights of way and sewer, water and electrical permits should be addressed during the screening process.

A corrective measure that institutionally complies with as many regulations as possible may be a more desirable choice since fewer permits and variances may be necessary upon installation. This in turn may facilitate the implementation process, which can aid in mitigating threats to human health and the environment by expediting cleanup.

Cost Considerations--

A detailed cost analysis should be performed for each proposed corrective measure to evaluate its overall cost effectiveness. This should include analysis of all direct and indirect capital costs that would be incurred during the implementation of the corrective measure. Also included should be any operating and maintenance costs that may be necessary to ensure the continued effectiveness of the measure. A present worth analysis should also be performed which allows the cost of a measure to be compared to a single present worth value. This value is equivalent to the amount of money that must be invested in a base year and disbursed as needed to cover the cost of the measure over its intended life. Overall cost effectiveness can be compared by examining the present worth value of each measure.

Selection

From the site investigation and the screening process a final decision concerning the most applicable corrective measure must be made. The permit writer must look at all aspects of the applicant's report including the completeness of the site investigation. As previously stated, much of the site investigation material may be readily available fom other investigations conducted at the site; however, the permit writer must ensure that available information properly characterizes all parameters that may affect the release and corrective measure implemented.

From the technology screening, the applicant should arrive at the most appropriate measure for remediation. The permit writer should be certain that the measure is adequately focused on the risk posed by the hazardous constituent release; i.e., that the endangerment or risk to human health and the environment is mitigated by the remedial action. The permit writer should evaluate the corrective measure in terms of each endangerment issue and should consider the effectiveness of the remedial action in mitigating migration from the soil horizon to other mediums such as ground water, surface water or the air.

Recommendation

If the permit writer is not completely satisfied that the applicant has properly addressed the issues in the site investigation and screening process, then the proposed corrective action plan should not be implemented. At this point the permit writer may convey to the applicant any deficiencies apparent in the site investigation or thought process in obtaining the corrective measure.

The permit writer may also suggest to the applicant other measures that he or she feels may be more applicable to the site in question. Pilot studies to evaluate the overall performance and effectiveness of a selected measure may also be suggested. Such studies can be very useful in recommending and selecting the corrective measure to be used for remediation.

Conceptual Design/Implementation

Once the corrective measure has been chosen, a detailed conceptual design must be completed prior to implementation.

Important activities which must be carried out during the implementation of the measure include field inspections to ensure quality control during construction, and to ensure that design specifications for construction and materials are being adhered to. Any alteration that occurs during construction must be investigated by an engineer to determine if it will affect the performance of the measure. These inspections during implementation must include monitoring to determine that contamination is being properly treated (i.e. to appropriate levels) or if being removed, that all contaminated soils are adequately excavated and disposed. These monitoring and inspection activities are important in ensuring that the corrective measure will perform as designed.

Monitoring

Upon completion of the corrective measure, a monitoring plan must be initiated to ensure that the corrective measure has been properly installed and is performing as specified. If failure or only partial success occurs, then monitoring data can be used to determine what further type of remediation may be necessary.

Monitoring can be done in both the upgradient and downgradient ground water through the use of monitoring wells to reveal if contamination is continuing to migrate into the ground water. Lysimeters can also be used to monitor the unsaturated zone for hazardous constituent concentration and migration. This type of monitoring can be very applicable to landfarm areas or below landfills or capped structures. Through the use of lysimeters, contamination can be detected prior to migration into the ground water. It may also be applicable to monitor the area through the use of soil borings to determine if contamination still remains in the soils and at what depths they occur. Air quality monitoring may also be applicable in many cases.

Table 5-2 presents a checklist of important considerations that should be addressed during the selection and implementation of a corrective measure. The final part of this section will use a case study presented in Section 4 to illustrate remedial actions taken for releases to soils.

SUMMARY

To assist the permit writer in reviewing applications for corrective measures for releases to soils, a summary table was generated. Table 5-3 illustrates the type of removal, disposal, treatment and containment corrective measures available for remediation of contaminated soils. The applicability of measures regarding site characteristics and amenable hazardous constituents are discussed in Section 3. Table 5-3 was developed from detailed technology/corrective measure discussions provided in Section 3 and case studies, presented in Section 4. The usefulness of this table can be illustrated by evaluating in detail, one of the case studies.

TABLE 5-2. PERMIT WRITERS' CHECKLIST

SITE NAME/LOCATION ____________________

Has an adequate site investigation been conducted concerning: (yes/no)

- Hazardous constituent characteristics ____
- Extent of contamination ____
- Soil considerations ____
- Site locations ____
- Site geology ____
- Site hydrology ____

Have all applicable corrective measures been adequately screened concerning technical issues? (yes/no)

- Performance ____
- Reliability ____
- Implementability ____
- Safety ____

Have public health considerations been adequately identified and addressed? (yes/no)

- Extent and nature of contamination ____
- Fate and transport of hazardous constituent(s) ____
- Exposure potential ____
- Contamination dose to receptors ____
- Frequency of exposure ____
- Toxicity of hazardous constituent(s) ____
- Risk assessment ____
- Proximity of local populations ____

Have environmental considerations been addressed during corrective measure screening and selection? (yes/no)

- Impact on surrounding environments ____
- Impact on human resources ____

Have institutional considerations been adequately addressed? (yes/no)

- Compliance or noncompliance with Federal regulations ____
- Compliance or noncompliance with State regulations ____
- Compliance or noncompliance with local regulations ____

Have accurate cost analyses been completed during the screening process? (yes/no) ____

(continued)

TABLE 5-2 (continued)

Selection of a corrective measure. (yes/no)

- Has an adequate site investigation been completed? ____
- Have screening parameters been properly addressed? ____
- Has the selection considered all available technologies? ____

Recommendation. (yes/no)

- Does the permit reviewer have recommendations for other corrective measures that may be more appropriate? ____

Has a conceptual design been adequately prepared? (yes/no) ____

Implementation: Are the following adequately characterized? (yes/no)

- Field inspections during construction ____
- Quality control check during construction ____
- Monitoring activities ____

Has an adequate monitoring plan been proposed in terms of: (yes/no)

- Soils ____
- Ground water ____
- Surface water ____
- Air ____

TABLE 5-3. SUMMARY OF SOIL REMOVAL/TREATMENT/CONTAINMENT (DISPOSAL) TECHNOLOGIES

Removal/Containment/Treatment Strategies	Removal/Containment (Disposal) Technologies				Treatment Technologies								Effectiveness/Comments
	Excavation	Offsite disposal	Onsite landfilling	Capping	Above-grade biodegradation	Onsite incineration	Offsite incineration	Solidification	In situ biodegradation	Photolysis	Neutralization	Sorption	
Removal/Containment	X			X									Ability to excavate the soils and hazardous constituent types influence the applicability of this technology. This technology does not comply with RCRA land disposal regulations due to the fact that there is no bottom liner/leachate collection system.
Removal/Disposal	X	X	X	X									Implementation is dependent on the ability to excavate the soils (refer to Section 3). Generally quite effective technologies, however replacement of containment unit is inevitable. Most effective and reliable when used in conjunction with treatment prior to disposal.
Removal/Treatment	X				X	X	X	X		X	X	X	Implementation is dependent on the ability to excavate the soils, and site specific, geologic and hydrologic parameters. Hazardous constituents dictate type of treatment that is applicable. Refer to Section 3 and Table 3-2 for hazardous constituents amenable to treatment.
In Situ Treatment								X	X	X	X	X	Effectiveness/implementation dependent upon site characteristics, geology, hydrology and hazardous constituents. Refer to the discussion in Section 3 and Table 3-2 concerning hazardous constituents amenable to treatment.

CASE STUDY EXAMPLE

The case study "Enterprise Avenue, Philadelphia, PA" will be considered in detail. By reviewing the technology discussions in Section 3, the applicability of the corrective measures implemented at this site can be assessed. This facility was a landfill used for disposal of incineration residues, flyash and debris by the city of Philadelphia. However, at some point drums of various industial and chemical wastes were illegally buried at the site. If applying for a RCRA permit, this type of situation would fit the description of a SWMU requiring corrective measures, as stated in Section 1 of this report.

The site characteristics appear to be quite well described. Site conditions dictate that a deep aquifer below the site is protected from contamination due to overlying silt and clay layers. This deep aquifer may recharge municipal ground water sources for New Jersey and, therefore, if contaminated could impact human health. A shallow and somewhat limited aquifer was, however, impacted by the contamination.

Remediation consisted of soil excavation including sampling and analysis to determine that contamination was adequately removed. Excavated soils that were found to be contaminated were disposed of offsite in an approved EPA facility. The site was then graded and capped with a low permeability clay. This remediation was reported to be successful. No ground water recovery or treatment was installed at this facility to clean up the contaminated shallow ground because the source was removed and the impermeable cap minimized further surface water infiltration through the site.

It is evident from information in this case study that soil contamination did not extend to great depths. An excess of 32,000 yd^3 of soils was removed which does not constitute an extremely large quantity of soil and therefore allows excavation to be an applicable technology. Removing the source of contamination through excavation in this case was also desirable because the deep confined aquifer may act as a recharge to a municipal water supply. Source removal would therefore minimize any future impacts and as stated in the case study shallow ground water is expected to clean itself up with time through volatilization, chemical or biological degradation and/or dilution and therefore not impact the deeper aquifer.

The corrective measures chosen for remediation at this facility appear to have been appropriate to mitigate the threat posed to human health and the environment. Removal followed by offsite disposal in an EPA approved facility is a common remedial measure although expensive and dependent upon offsite landfill capacities.

By referring to Table 5-2, it is evident that the removal/disposal corrective measures implemented at the site for remediation of contaminated soils are applicable. Further review of Section 3, which discusses corrective measures and Table 3-2 which provides information concerning wastes amenable to various treatment technologies verifies this fact.

REFERENCES*

Alexander, M. Introduction to Soil Microbiology, Second Edition. John Wiley and Sons, New York, NY. 1977.

Bonazountas, M., and J. Wagner. "SESOIL - A Seasonal Soil Compartment Model" Prepared for U.S. Environmental Protection Agency, Office of Toxic Substances, Washington, D.C. 1981.

Bonner, et al. "Engineering Handbook for Hazardous Waste Incineration." Prepared for U.S. Environmental Protection Agency. June 1981. SW-889.

Callahan, M., et al. "Water Related Environmental Fate of 129 Priority Pollutants," Volumes I and II. Prepared for U.S. Environmental Protection Agency, Office of Water Planning and Standards, Washington, D.C. December 1979. EPA-440/4-79-029a and b.

Callahan, M. A., R. H. Johnson, J. L. McGinnity, et al. "Handbook for Performing Exposure Assessments." Draft Report. Prepared for U.S. Environmental Protection Agency, Office of Health and Environmental Assessment, Washington, D.C. 1983.

Chiou, C. T., et al. "Partition Coefficient and Bioaccumulation of Selected Organic Chemicals," 11,475. Environmental Science and Technology. 1977.

Chiou, C. T., L. J. Peter, and V. H. Freed. "A Physical Concept of Soil Water Equilibria for Nonionic Organic Compounds," 206, 831. Science. 1979.

Chiou, C. T., P. E. Porter, and D. W. Schmedding. "Partition Equilibria of Nonionic Organic Compounds Between Soil Organic Matter and Water," 17, 227. Environmental Science and Technology. 1983.

Ciriello, J. U.S. Environmental Protection Agency, Region I. Telephone Conversations with L. Farrell, GCA/Technology Division, Re: Silresim Site. May and July 1985.

Crosby, D. G., and A. S. Wong. "Photodecomposition of Chlorinated Dibenzo-o-dioxins," Vol. 173, pp. 748-749. Science. August 20, 1971.

D'Appolonia Waste Management Services, ERT, Inc., and BFI. "Final Report: Feasibility Study - Crystal Chemical Company, Houstin, Texas." Prepared for the U.S. Environmental Protection Agency and the Texas Department of Water Resources. June 1984.

Dean, J. A. (Ed.). Lange's Handbook of Chemistry, Twelfth Edition. McGraw-Hill Book Company, New York. 1979.

DeRenzo, D. J. "Biodegradation Techniques for Industrial Organic Wastes from Pollution Technology Review." No. 65, 158. Chemical Technology Review, Noyes Data Corporation, Park Ridge, NJ. 1980.

Dilling, W. L., C. J. Bredeweg, and N. B. Tefertiller. "Organic Photochemistry: Simulated Atmospheric Photodecomposition Rates of Methylene Chloride, 1,1,1-Trichloroethane, Trichloroethylene, Tetrachloroethylene, and Other Compounds," 10, 351. Environmental Science and Technology. 1976.

Dragun, J., and C. S. Helling. "Soil- and Clay-Catalyzed Reactions: I. Physiochemical and Structural Relationships of Organic Chemicals Undergoing Free-Radical Oxidation." Land Disposal of Hazardous Waste. Proceedings of the Eighth Annual Research Symposium, 1982. EPA-600/9-82-002.

E. C. Jordan, 1985. "Corrective Measures for Releases to Surface Water." Prepared for U.S. Environmental Protection Agency, Office of Solid Waste, Washington, D.C. August 1985. EPA Contract No. 68-01-6871.

EPA, 1980. "Guide to the Disposal of Chemically Stabilized and Solidified Waste." Washington, D.C. September 1980. SW-872.

EPA, 1981a. Remedial Actions at Hazardous Waste Sites: Survey and Case Studies, Whitmoyer Laboratories. January 1981. EPA-430/9-81-05. SW-910.

EPA, 1982a. "Graphical Exposure Modeling System (GEMS) User's Guide." Draft Report. Prepared for U.S. Environmental Protection Agency, Office of Pesticides and Toxic Substances. Washington, D.C. 1982.

EPA, 1982b. "Handbook for Remedial Action at Waste Disposal Sites." June 1982. EPA-625/6-25-006.

EPA, 1984a. "Case Studies: Remedial Response at Hazardous Waste Sites." Fairchild Republic Company. February 1984. EPA-540/2-84-002.

EPA, 1984b. "Review of In-Place Treatment Techniques for Contaminated Surface Soils." Prepared by JRB Associates, Arthur D. Little, Inc. and Utah Water Research Laboratory. September 1984. EPA-540/2-84-003a.

EPA, 1984c. "Proposed Guidelines for Exposure Assessment." Federal Register, Nov. 23, 1984, 49 46314. U.S. Environmental Protection Agency, Office of Health and Environmental Assessment. 1984.

Follett, R. H., L. S. Murphy, and R. L. Donahue. Fertilizers and Soil Amendments. Prentice-Hall, Inc., Englewood Cliffs, NJ. 1981.

Forstner, U. and G. T. W. Wittman. Metal Pollution in the Aquatic Environment. Springer-Verlag. Berlin. 1979.

GA Technologies. Telephone Conversation with R. Bell, GCA Corporation/Technology Division. Re: Fluidized Bed Incineration. June 5, 1985.

GCA Corporation/Technology Division, 1983a. "Development of Protocols for Ambient Air Sampling and Monitoring at Hazardous Waste Facilities: Methods Summary Report." Draft Report. Prepared for the U.S. Environmental Protection Agency, Office of Solid Waste, Land Disposal Branch. EPA Contract No. 68-02-3168.

GCA Corporation/Technology Division, 1983b. "Evaluation and Selection of Models for Estimating Air Emissions from Hazardous Waste Treatment, Storage, and Disposal Facilities." Revised Draft Final Report. Prepared for the U.S. Environmental Protection Agency, Office of Solid Waste, Land Disposal Branch. EPA Contract No. 68-02-3168.

GCA Corporation/Technology Division, 1983c. "State of New Jersey Incinerator Study Volume I: Technical Review and Regulacory Analysis of Industrial and Hazardous Waste Incineration," Final Report. June 1983.

GCA Corporation/Technology Division, 1984b. "Task I: Site Investigations Analysis Report - Frontenac Site", Detailed Review Draft. Office of Waste Programs Enforcement, Washington, D.C. Contract No. 68-01-6789. October 1984.

GCA Corporation/Technology Division, 1985a. "Corrective Measures for Releases to Ground Water from Solid Waste Management Units", Draft Final Report. Prepared for U.S. Environmental Protection Agency, Office of Solid Waste, Land Disposal Branch. Washington, D.C. August 1985. EPA Contract No. 68-01-6871.

GCA Corporation/Technology Division, 1985b. "Technical Guidance for Corrective Measures -- Identifying Air Releases." Prepared for the U.S. Environmental Protection Agency, Office of Solid Waste, Land Disposal Branch. Washington, D.C. June 1985. EPA Contract No. 68-01-6871.

Gilrein, S. U.S. Environmental Protection Agency, Region VI. Telephone Conversations with L. Farrell, GCA Corporation/Technology Division, Re: Crystal Chemical Site. May and July 1985.

GSX Corporation. Telephone Conversation with S. Konieczny, GCA Corporation/Technology Division, Re: Disposal Costs. March 1985.

Hasel, Dr. R. U.S. Environmental Protection Agency, Region VII. Telephone Conversation with M. Jasinski, GCA Corporation/Technology Division, Re: EPA-ORD Mobile Incinerator. August 1985.

Hernandez, R. U.S. Environmental Protection Agency, Region III. Telephone Conversations with L. Farrell, GCA Corporation/Technology Division, Re: Enterprise Avenue Site. May, June, and July 1985.

Howard, P. H., et a. "Review and Evaluation of Available Techniques for Determining Persistence and Routes of Degradation of Chemical Substances in the Environment." May 1975. EPA-560/5-75-006.

Huber, J. M. Telephone Conversation with P. Hughes, GCA Corporation/Technology Division, Re: Advanced Electric Reactor. 1985.

ICF Incorporated, 1985. "Superfund Health Assessment Manual." Prepared for the U.S. Environmental Protection Agency, Office of Emergency and Remedial Response, Washington, D.C. May 22, 1985. EPA Contract No. 68-01-6872.

JRB Associates, 1982. "Techniques for Evaluating Environmental Processes Associated with the Land Disposal of Specific Hazardous Materials," Vol. I: Fundamentals. Report to U.S. Environmental Protection Agency, Office of Solid Waste. 1982.

Kowalenko, C. G. "Organic Nitrogen, Phosphorous and Sulfuring Soils," pp. 95-135. *Soil Organic Matter*. M. Schnitzer and S. U. Khan, (Eds.). Elsevier Scientific Publishing Co., New York, NY. 1978.

Lanier, J., Energy Systems Company, El Dorado, Arkansas. Telephone Conversation with R. Bell, GCA Corporation/Technology Division, Re: Mobile Rotary Kiln Incinerator. June 1983.

Life Systems, Inc. "Endangerment Assessment Handbook." Prepared for the U.S. Environmental Protection Agency, Office of Waste Programs Enforcement, Washington, D.C. June 7, 1985. EPA Contract No. 68-01-7037.

Lopez-Avila, V. "Organic Compounds in an Industrial Wastewater: A Case Study of their Environmental Impact." Doctoral Thesis. MIT. 1979.

McLean, E. O. "Soil pH and Lime Requirement," pp. 199-224. *Methods of Soil Analysis; Part 2 - Chemical and Microbiological Properties*, Second Edition. A. L. Page (Ed.). Americal Society of Agronomy, Inc., Madison, WI. 1982.

McNells, D. N., D. C. Barth, M. Khare, et al. "Exposure Assessment Methodologies for Hazardous Waste Sites." Las Vegas, NV: Office of Research and Development, Environmental Monitoring Systems Laboratory. CR810550-01. 1984.

Milanowski, J. and R. Scholz. "Mobile System for Extracting Spilled Hazardous Materials from Excavated Soils." *Control of Hazardous Materials Spills*, Milwaukee, Wisconsin. 1982.

Mullen, D., SCA Chemical Services, Chicago, IL. Telephone Conversation with R. Bell, GCA Corporation/Technology Division, Re: Rotary Kiln Incinerator. June 1985.

Murphy, G., Rollins Environmental Services, Deer Park, Texas. Telephone Conversation with R. Bell, GCA Corporation/Technology Division, Re: Rotary Kiln Incinerator. April 1985.

Nagel, G., et al. "Sanitation of Ground Water by Infiltration of Ozone Treated Water," 123(8):399-407. GWF - Wasser/Abwasser. 1982.

Parr, J. F., et al. "Factors Affecting the Degradation and Inactivation of Waste Constituents in Soils." Land Treatment of Hazardous Wastes. Noyes Data Corporation, Park Ridge, New Jersey. 1983.

Radian Corporation. "Evaluating Cost-Effectiveness of Remedial Actions at Uncontrolled Hazardous Waste Sites," Draft Methodology Manual. Prepared for the U.S. Environmental Protection Agency. January 10, 1983.

R. S. Means Co., Inc. 1985 Means Site Work Cost Data, 4th Annual Edition. 1985.

Ronyak, B., Polybac Corporation. Telephone Conversation with S. Konieczny. GCA Corporation/Technology Division. June 1985.

Roy, F. Weston, Inc. "Construction Phase Summary Report, Remedial Action Program - Phase II for the Excavation and Disposal of Hot-Spot Soil From, and Closure of, the Enterprise Avenue Site, Philadelphia, Pennsylvania." April 1985.

Schultz, H. L., W. A. Palmer, G. H. Dixon, et al., Versar Inc." Superfund Exposure Assessment Manual," Final Draft Report. Prepared for U.S. Environmental Protection Agency, Office of Toxic Substances, Office of Solid Waste and Emergency Response, Washington, D.C. August 17, 1984. EPA Contract Nos. 68-01-6271 and 68-03-3149.

SCS Engineers. "Cost of Remedial Actions at Uncontrolled Hazardous Waste Sites." Prepared for the U.S. Environmental Protection Agency, Cincinnati, Ohio. April 1981.

Sobotka, Inc. "Phase I Corrective Action Guidance: Information and Methodology for Identifying Releases from Solid Waste Management Units," Draft Report. April 19, 1985. EPA Contract No. 68-01-6871.

Sweeney, K. "Reductive Treatment of Industrial Wastewaters: I. Process and Description and II. Process Application," pp. 67-78. Water 1980. G. F. Bennett (Ed.). American Institute of Chemical Engineers Symposium, Series 209(77). 1981.

Twehey, J. D., J. E. Sevee, and R. L. Fortin. "Silresim:" A Hazardous Waste Case Study." Hazardous Materials Control Research Institute. Proceedings of the National Conference on Management of Uncontrolled Hazardous Waste Sites. Washington, D.C. October 31 to November 2, 1983.

Thagard Research Corporation. "Mobile High Temperature Fluid Wall Reactor," Draft Report. 1984.

Thibault, G. T., and N. W. Elliott. "Biological Detoxification of Hazardous Organic Chemical Spills," pp. 398-402. Control of Hazardous Material Spills. Vanderbilt University, Nashville, TN. 1980.

Thibodeaux, L. J. Chemodynamics: Environmental Movement of Chemicals in Air, Water, and Soil. Wiley-Interscience, John Wiley & Sons. New York. 1979.

Traver, R. U.S. Environmental Protection Agency. Telephone Conversation with S. Konieczny, GCA Corporation/Technology Division, Re: U.S. EPA Units Available for Remediation of Contaminated Soils. May 1985.

Versar, Inc. "Site Selection Worksheets." Prepared for U.S. Environmental Protection Agency, Hazardous Waste Engineering Research Laboratory, Cincinnati, Ohio. February 25, 1985. EPA Contract No. 68-03-3235.

Verscheuren, K. Handbook of Environmental Data on Organic Chemicals, Second Edition. Van Nostrand Reinhold, New York. 1983.

Weast, R. C. (Ed.). CRC Handbook of Chemistry and Physics, 58th Edition. The Chemical Rubber Co., Cleveland, OH. 1977-1978.

Woodrow, J. E., D. G. Crosby, and J. N. Seiber. "Vapor-Phase Photochemistry of Pesticides." 85:111-125. Residue Reviews. 1983.

---

*References for Appendices A and B are included in this reference list.

APPENDIX A

FATE AND TRANSPORT

Hazardous constituents released to soil have the potential to migrate from the original point of release. This movement may be within or by means of the soil medium, or the constituents may migrate from the soil into another medium, such as air, ground water, or surface water. In addition, the hazardous constituents released to these media may also be subject to degradation or removal mechanisms that decrease the amount of the contaminants in the soil. Alternatively, the hazardous constituents may be resistant to such degradation and may persist in the environment. An estimate of the mobility and persistence of a contaminant within the particular soil environment is key to evaluating the potential risk posed by the release. Such information provides the basis for performing the exposure assessment described in Appendix B. In addition to determining exposure potentials and characterizing risk, one must also be able to assess potential movement within and between environmental media to determine appropriate corrective actions to be applied to the release.

The following sections provide a brief description of the factors influencing contaminant transport and fate and the mechanisms by which hazardous constituents may be transported or degraded. Guidelines are provided to assist the permit writer in evaluating chemical and physical parameters of hazardous constituents with respect to their potential transport and fate from soil releases. Generalizations of environmental behavior for selected chemical classes are also provided. Other site-specific, environmental factors that would influence hazardous constituent transport and fate are listed for consideration in assessing actual releases.

FACTORS AFFECTING TRANSPORT AND FATE

Mechanisms Affecting Transport

A number of environmental transport and attenuation mechanisms that are applicable to soil contaminant releases are influenced by physical and chemical properties of the hazardous constituent. Additionally, soil conditions and other environmental factors will influence the action of these mechanisms on a site-specific basis. A general description of these transport mechanisms follows:

Adsorption--

Adsorption to soil materials can immobilize contaminants or slow their movement through soil (attenuation). Factors influencing adsorption include soil types, charged sites and ion exchange capacity of the soil materials, structure and charge of the hazardous constituents released, and chemical solubility and volatility. Tendency for adsorption to soil organic matter can be estimated for some organic chemicals by using the log of the octanol/water partition coefficient (K_{ow}). In addition, high solubility or volatility could be expected to decrease adsorption tendency; therefore, these parameters should be evaluated.

Volatilization--

Volatilization from soil may occur at soil surfaces or through pore spacings in unsaturated soils. This mechanism may remove hazardous constituents from the soil medium via transport into the air medium or may be a means by which contaminants move through the unsaturated soil medium. Factors influencing volatilization include soil pore space size, adsorption to soil, aqueous solubility (in wet soils), and general volatility. Physical and chemical parameters that can be used to estimate potential to volatilize from/in soils include vapor pressure, K_{ow}, aqueous solubility, and Henry's Law constant. The Henry's Law constant expresses the equilibrium distribution of a compound between air and water and indicates the relative ease with which the compound may be removed from aqueous solution. None of the individual parameters is adequate to predict volatilization from/in soil owing to the complexity of the medium; rather, the factors considered together produce a general overview of likely behavior.

Dissolution--

Dissolution or solubilization of organic and inorganic hazardous constituents may occur in the presence of water from rainfall or other contaminants present (solvents) that result from co-release of such materials. For inorganics, dissolution will depend primarily on the solubility of the compound form released, and the pH and ionic strength of the rainfall or solvent solution introduced. Solubility data for inorganic constituents can be found in standard reference works of Weast (1977-78) and Dean (1979). For organic constituents, aqueous solubility values are also often available from standard reference works. In addition, the K_{ow} can be used to assess a compound's relative preference for the neutral organic phase (octanol) and the polar aqueous phase (water). This can be used as an indicator of potential migration induced by infiltrating rainwater/solvents relative to a compound's tendency to remain adsorbed onto soil organic matter.

Mechanisms Affecting Fate

Another group of mechanisms to which hazardous constituents may be subjected are primarily involved in determining the environmental fate of these compounds. Rather than directing the migration of the compounds within and between media, these fate mechanisms determine persistence or rates of degradation. In general, susceptibility of hazardous constituents to these fate mechanisms is documented by empirical evidence (case studies and research projects) rather than prediction based on physical/chemical parameters. If such empirical information is not available in chemical profiles or Callahan et al. (1979), some generalizations can be made based on compound class, chemical structure, and using some physical and chemical properties for support. Because of the complexity in assessing the significance of environmental fate mechanisms, each is discussed in some detail with general guidelines provided, where possible. In most cases, however, it is more relevant to discuss the significance of the mechanisms in a given medium to the individual compound class or type; as appropriate, this is the approach followed here.

Biodegradation--

Biodegradation can occur in the soil medium or in aqueous media to which hazardous constituents may be transported. The most important factor to consider in evaluating the role of biodegradation is that it is dependent on local environmental conditions and a native microbial population capable of metabolizing the hazardous constituents of concern. Therefore, it may not occur at any given site, and its occurrence would be difficult to predict without bench scale tests.

Surface and shallow soils are generally expected to support aerobic degradation due to their proximity to the atmosphere and high oxygen levels. Deeper soils (in the saturated zone) may support either aerobic or anaerobic degradation depending on dissolved oxygen levels in the associated ground water.

Factors which influence the rate of biodegradation in soil include: amount of water present; temperature; soil pH; aeration or oxygen supply; nutrient availability (N,P,K,S); soil texture and structure; and the nature of indigenous microflora (if any). In addition, properties of the hazardous constituents (i.e., wastes) themselves as they interact with soil are important and include: chemical composition; physical state (liquid, slurry, or sludge); carbon:nitrogen ratio; water content and solubility of waste; chemical reactivity or dissolution effects of the waste on the organic matter present in the soil; volatility; pH of the waste; biological oxygen demand (BOD); and chemical oxygen demand (COD). This information is more readily available in literature on land treatment, and is of greater utility for land farming situations than for releases from other types of SWMUs. For further information on the relevance of these waste and soil characteristics to biodegradability refer to Parr, et al. (1983); this document is, however, primarily directed at land farming operations.

A more general discussion and overview on biodegradation is provided in DeRenzo (1980) as the result of experimentation on chemical mixtures. Generalities of biodegradability (DeRenzo, 1980) are as follows:

- Nonaromatic or cyclic compounds are preferred over aromatics.

- Materials with unsaturated bonds in their molecules (e.g., alkenes, alkynes, tertiary amines, etc.) are preferred over materials exhibiting saturated bonding.

- The comparative stereochemistry of certain compunds make them more or less susceptible to attack by microbial enzymes. The n-isomers of the lighter weight molecules are preferred over branched isomers and complex polymeric substances.

- Soluble organic compounds are usually more readily degraded than insoluble materials. Biological waste treatment is most efficient in removing dissolved or colloidal materials which are more readily attacked by enzymes and transported through cell membranes. Readily dispersed compounds are usually degraded more rapidly because of the increased surface area that is presented to the individual microorganisms.

- The presence of key functional groups at certain locations in the molecules can make a compound more or less amenable to biodegradation. Alcohols, for example, are often more readily degraded than their alkane or alkene homologues. On the other hand, halogenation of certain hydrocarbons may make them resistant to degradation.

Similar generalities correlating substituent groups and biodegradability (Howard, 1975) are as follows:

- Alcohols, aldehydes, acids, esters, amides, and amino acids appear to be more susceptible to microbial attack and breakdown than the corresponding alkanes, olefins, ketones, dicarboxylic acids, nitriles, amines, and chloroalkane groups.

- Meta-substituted phenols were found to be usually more resistant to biodegradation than the ortho- or para-isomers.

Photolysis--

Photolysis is primarily a significant fate mechanism only for organic compounds in the air medium. However, photolysis may also occur on soil surfaces or in shallow surface waters to the depth of penetration of sunlight. Alteration or degradation of organic constituents may occur by direct or indirect photolysis. Direct photolysis is the reaction of the compound as a result of its absorbing ultraviolet (UV) radiation. Indirect, or sensitized, photolysis occurs when the UV energy is transferred via another chemical species.

Predicting a hazardous constituent's potential for photodegradation requires a knowledge of that constituent's tendency to absorb UV light. Some reference works on compound degradation (Callahan, et al, 1979) contain information on priority pollutant compounds including UV absorption maxima for many. Having an absorption maximum in the UV range could indicate potential for photodegradation.

Empirical information on environmental photolysis is usually limited to photo-oxidation in the ambient atmosphere. These studies done in smog chambers and in the presence of oxidants such as nitric oxide (NO) and ozone are not relevant to photolysis of hazardous constituents in soil, primarily because such oxidants would not be present at the soil surface. Photolysis would not be expected to be a significant fate mechanism for hazardous constituents in soil; rather, it could be important for constituents that have volatilized from soil.

Oxidation--

Chemical oxidation of organic compounds, for the most part, uses mechanisms which involve free radicals or singlet oxygen compounds. Generally, phenols, aromatic amines, olefins and dienes, and alkyl sulfides are the most susceptible to oxidation in soil and water systems. Oxidation of saturated compounds and their haloalkane, alcohol, ketone, and ester derivatives occurs slowly in these media and is not significant as a fate mechanism for these compound classes (Dilling et al, 1976).

Oxidation of inorganics is dependent on the presence of compounds in the soil capable of oxidizing the inorganic hazardous constituents released. In general, extremely strong oxidizers will not be present in soil because of their rapid reaction with moisture or soil organic matter. Of primary concern would be oxidizers co-released with other hazardous constituents. If proper handling and disposal practices have been followed, this event would be unlikely. Refer to 40 CFR Part 264, Appendix V, for examples of potentially incompatible wastes, including oxidizers. It should be noted for inorganics, particularly elemental metals, that oxidation would tend to dissolve the hazardous constituent and permit mobilization into the aqueous phase rather than resulting in its degradation.

Precipitation--

Precipitate formation is the interaction of dissolved species that exceed their solubility product constant (K_{sp}) and form a solid that settles out of solution. Precipitates of metal ions that are most likely to occur in the environment are sulfides, carbonates, and hydroxides that will form when these anions are present at elevated concentrations. Precipitate formation is also dependent on temperature and pH.

The tendency for metal precipitates to form in a given environment can be used as an indicator of potential attenuation of metal-containing releases. Metals that are compound forms of sulfides, carbonates and hydroxides are likely to transport more slowly than more soluble metal salts. These latter compound types could be leached more readily by rainwater infiltration through soils and could thereby be transported to the ground water medium.

Hydrolysis--

Hydrolysis of organic compounds can result from a neutral reaction with water, or it can be catalyzed in the presence of an acid or a base, with the end result being the replacement of a functional group (-X) by a hydroxyl group (-OH). In soils, the structure-activity rates for hydrolysis are hard to predict. They depend on complex pH conditions at the soil surface, the influence of metal-ion catalysis, and the presence of such functional groups as phenols, amines, or sulfides in the soil which could lead to catalysis.

PHYSICAL AND CHEMICAL PROPERTIES AFFECTING BEHAVIOR

A number of physical and chemical properties of a hazardous constituent can be used as indicators of the compound's probable environmental behavior. It should be recognized that these properties are most relevant to the transport mechanisms such as adsorption, volatilization, and dissolution. Most are only pertinent to organic compounds and classes; an exception is aqueous solubility which is also important (and available) for inorganic compounds. The most useful properties and their application to assessing potential envrionmental transport are described in some detail with examples of their use given as appropriate. To actually find the values of the parameters for hazardous constituents that may be released from SWMUs, refer to the Health Effects Assessments (HEAs) prepared for the Office of Emergency and Remedial Response (OERR) or the Toxicity Profiles prepared for OWPE. These profiles contain chemical/physical property data, information on toxicity and other health hazards, and as available, information on environmental transport and fate. Additional sources of portions of this information are Callahan, et al. (1979), Verscheuren (1983), Dean (1979), and Weast (1977-78). The last two references will be very important for obtaining solubility data specific to inorganic compound forms.

Vapor Pressure

Vapor pressure is the pressure exerted by a gas in equilibrium with its solid or liquid state at a given temperature. Generally, values are reported for 20° to 25°C, typical ambient air temperatures, and consistent with evaluating the transport of hazardous constituents released to soils. Vapor pressure values are for the pure compound and represent maximum values under equilibrium conditions; the vapor pressure of a chemical is always lowered when it is dissolved in another substance. However, vapor pressure can be used as an indication of the volatilities of hazardous constituents released. High vapor pressure (>10 torr) would suggest significant potential to volatize while low vapor pressure (<0.01 torr) suggests low volatility. By combining vapor pressure data with aqueous solubility and adsorption tendency, one can determine whether a constituent is more likely to be transported in the air, water or soil medium, thereby providing focus in the evaluation of a constituent's likely movement and environmental fate.

Vapor Density

Vapor density describes the mass per unit volume of a gas at its equilibrium vapor pressure as described above. It is often given relative to the density of air, defined as unity, so that one can determine the behavior of the gas upon release from the solid or liquid phase. If the density is significantly greater than unity, the gas will remain at the surface of the source and will be transported along the ground. If toxic in nature, it may thereby pose a potential health hazard. If the vapors are released below soil surface, they may remain there rather than rising through the pore spacings to volatilize away from the surface soils. If the vapor density is less than or equal to unity, the gas will rise and disperse easily.

Water Solubility

Water solubility describes the mass of a compound that dissolves in or is miscible in water at a given temperature and pressure, usually 20° to 25°C and one atmosphere, and usually expressed in mg/L or ppm. Water solubility is important because it indicates a compound's affinity for the aqueous medium. High water solubility permits greater amounts of the compound to enter the aqueous phase and, therefore, be removed from the soil environment. High solubility is indicative of an increased tendency to leach from soil media while low solubility would indicate a tendency to remain adsorbed onto the solid phase (i.e., soil). This property is particularly significant when determining whether a release will remain relatively immobile on soil in the unsaturated zone or whether it will migrate readily to the saturated zone via rainwater infiltration. Solubility can be used to establish the potential of a hazardous constituent to enter and remain in the hydrological cycle. One might then focus on movement and reactions of the constituent in ground and surface waters rather than pursuing volatilization and soil adsorption as primary transport mechanisms and thus potential exposure routes.

Aqueous solubility can also be related to fate mechanisms including biodegradation. Compounds having high aqueous solubility are generally more biodegradable than insoluble compounds, because the former are more readily available to microorganisms in aqueous media. Compounds with low aqueous solubility are often less biodegradable and tend to bioaccumulate and adsorb to soil organic matter.

Log Octanol/Water Partition Coefficient

The log of the octanol/water partition coefficient (K_{ow}) is a measure of the relative affinity of a compound for the neutral organic and inorganic phases represented by n-octanol and water, respectively. It is calculated from a ratio (P) of the equilibrium concentrations (C) of the compound in each phase:

$$P = \frac{C_{octanol}}{C_{water}}, \text{ and } K_{ow} = \log P.$$

The K_{ow} has been directly correlated to a number of factors for determining environmental fate and transport. These include adsorption on soil organic matter, bioaccumulation, and biological uptake (Chiou, 1983, 1979 and 1977). It also bears an inverse relationship to aqueous solubility. The K_{ow} of a hazardous constituent is very important for evaluation of adsorption on various soil types with its resulting effect on degradation. The greater the soil adsorption and immobilization, the slower the constituent will transport to aquifers and surface waters. Organic constituents with an aqueous solubility of less than 5 ppm and K_{ow} of greater than 5 tends to accumulate in river sediments (Lopez-Avila, 1979), and some degree of adsorption on soil organic matter would be expected for constituents with moderate solubility (approximately 1,000 ppm) and $K_{ow} = 2$. It is essential to note that K_{ow} indicates potential for adsorption only on the organic matter portion of a particular soil or sediment. It does not correlate to adsorbability by soils that are primarily inorganic (i.e., clays and minerals).

To use a constituent's K_{ow} to determine environmental transport and fate, one should determine whether soils near the release are likely to have low, medium, or high organic matter content. This is discussed in more detail later in this section. If sufficient organic matter is present at the release location to suggest possible adsorption, one should then examine the K_{ow} of the hazardous constituent released. If the K_{ow} is less than 2, adsorption will not be a significant attenuation mechanism for the hazardous constituent. If K_{ow} is between 2 and 4, some adsorption may occur; and if K_{ow} is greater than 4, adsorption onto soil organic matter is expected to be significant in immobilizing the hazardous constituent.

Henry's Law Constant

The Henry's Law constant of a compound is the relative equilibrium ratio of a compound in air and water at a constant temperature. It is more significant to releases to water but may be considered where water is present on the soils or accumulated nearby. The Henry's Law constant can be estimated using the vapor pressure, aqueous solubility, and molecular weight of the compound (Thibodeaux, 1979). It is often reported in units of atm-m^3/mole. The Henry's Law constant expresses the equilibrium distribution of the compound between air and water and indicates the relative ease with which the compound may be removed from aqueous solution. Increasing value of the Henry's Law constant indicates increasing favorability of volatilization as a transport mechanism. In addition, the constant provides more information than a comparison of vapor pressure and aqueous solubility. It is emphasized, however, that this constant is representative of equilibrium conditions for a pure chemical compound and may not accurately predict behavior under actual environmental conditions.

Other Physical Properties

Several additional physical properties influence environmental behavior and can be used to supplement evaluations based on the properties discussed above. Two of these properties, melting point and boiling point, are obvious in their use. These two properties indicate the physical state of the hazardous constituent at standard conditions. This will be the basis for looking at how a hazardous constituent release may migrate. Use of physical state information is discussed later in this section.

Molecular weight is another property that can be used to assess potential transport if more specific chemical and physical property data (i.e., K_{ow}, Henry's Law constant) are not available. The use of molecular weight in assessing hazardous constituent transport and fate is somewhat less obvious than for some properties, and warrants a brief discussion. Molecular weight relates to the size and density of the molecules of a compound. All other factors being equivalent (i.e., adsorptive surface, compound polarity, atomic charge, etc.), a higher molecular weight, and thus larger compound, will adsorb more strongly to another material than will a smaller compound. Therefore, if one could generalize behavior by assigning a constituent to a particular structural class, one could (based on size) extrapolate behavior of the constituent in question relative to those members of the class for which empirical data are available. It should be noted that molecular weight is only a secondary factor in assessing adsorption and that it should only be used in conjunction with other constituent properties.

Viscosity is another physical property that will significantly influence hazardous constituent migration in the soil medium. Liquid compounds with high viscosity would move more slowly through soil than would liquids with low viscosity. However, to obtain numerical values of this property, one would have to access reference works that may not be readily available. Therefore, it is recommended that the reader consult the HEAs or toxicity profiles for the hazardous constituent in question to determine whether the general description provides an indication of viscosity. It is probable that constituents exhibiting high viscosity will be so noted. Otherwise, a conservative assumption is that the viscosity would be comparable to water and that the liquid hazardous constituent would potentially move through soil at a rate comparable to water.

ASSESSMENT OF HAZARDOUS CONSTITUENT TRANSPORT AND FATE

Hazardous constituent transport and fate is a highly complex process and cannot be accurately predicted with information that is readily available. However, by combining information on the chemical and physical characteristics of the hazardous constituents released with site-specific information, such as soil types, climate, and release area activity patterns, it is possible to generalize potential transport and fate. This can then provide the basis for estimating potential exposure and risk posed by the release; it can also direct the efforts of further data gathering to focus on locations and media of primary concern. The following is a summary of items to be considered in assessing potential transport and fate of a hazardous constituent release. It attempts to lay out in step-wise fashion a logical approach to collecting and evaluating relevant information. It is not intended to provide exact answers for all constituent releases.

Type of Hazardous Constituent Released

- Does this hazardous constituent belong to a class or type of compound for which previous environmental behavior has been documented or postulated?

  - Very often, if a constituent can be classified or grouped with similar compounds, for which empirical data are available, the behavior of an unknown constituent can be estimated based on these structural or physiochemical similarities. Table A-1 lists organic compound classes and generalizes what is known or postulated about their environmental behavior following release to soils. Inorganic hazardous constituents are primarily metals, and their environmental behavior cannot as easily be generalized. Therefore, they have not been addressed in this table, but guidance on clay sorption and humic complexes of metals are provided later in this section.

- What are the physical and chemical properties of the constituent(s) which may influence transport and fate?

  - As previously discussed, certain physical and chemical properties can be used to estimate transport of a constituent following release to soil. Table A-2 lists some of these properties and broadly applies ranges of values that may result in the specified behavior. Note that other factors such as the presence of certain functional groups and site-specific environmental factors may alter actual transport from that expected when considering only physical and chemical properties. Relevant properties for individual chemicals can be found in HEAs available from OERR, Callahen et al. (1979), Verscheuren (1983), Weast (1977-78), and Dean (1979).

- What is the physical form of the hazardous constituent(s) released?

  - Whether the release is liquid, solid or semisolid, such as sludge, the physical form of the release can strongly influence transport. If the release is a solid and remains solid under ambient conditions, then it could remain on the soil surface unless mobilized by dissolution in rainwater or other hazardous constituents (solvents) or by entrainment in ambient air (as could be caused by wind or similar action). If the release is a liquid, it is likely to move below the soil surface at rates dependent on its viscosity and adsorptive tendencies. If the release is a semisolid, it may separate into two phases that will tend to be mobilized at different rates and possibly by different mechanisms.

Location of Release

- Characterize the location of the release as fully as possible. Use the categories below for guidance.

  - chemical activity - What chemicals used in the area could act to mobilize the hazardous constituent released? Have any such chemicals been released in the area where the hazardous constituent(s) in question were released? What are the chances of future releases of solvents in the same area? Chemicals of concern would include:

TABLE A-1. GENERAL SUSCEPTIBILITY OF SELECTED ORGANIC COMPOUND CLASSES TO MECHANISMS AFFECTING TRANSPORT AND FATE

Compound Class	Adsorption	Volatilization	Leaching	Biotransformation	Chemical Reaction
Aliphatic hydrocarbons	Low to moderate	High	Moderate to high	Low to moderate	Generally very slow in soil
Aromatic hydrocarbons	Low to moderate	Moderate to high	Moderate to high	Low to moderate	Generally very slow in soil
Halogenated aliphatics	Low to moderate	High	Moderate to high	Low to moderate	Generally very slow in soil
Halogenated aromatics	Low to moderate	Moderate to high	Moderate to high	Low to moderate	Generally very slow in soil
Phenols	Low to moderate	Low	High	Moderate	Low to moderate
Chlorophenols	Low to moderate	Low	High	Low to moderate	Low to moderate
Nitro/nitroso compounds	Low to moderate	Low	Moderate to high	Varies with compound; most low; residues 2 to 10 months in soil	Moderate
Amines/amides	Low to moderate	Low	Moderate to high	Varies with complexity of compound; simpler are more readily degraded	Possible; significance unknown
Cyanides/azo compounds	Low to moderate	Low except in presence of acid or for cyanogen halide compounds	High	Low to moderate	Possibly moderate
Bi-phenyl compounds	High	Low	Low	Low	Low
Polynuclear aromatics (PAHs)	Moderate to high	Low	Moderate	Low to moderate	Low to moderate
Cyclodiene pesticides	Moderate to high	Low	Low	Low; transformations occur within the cyclodiene class	Very slow; transformations occur within the cyclodiene class
Carbamate insecticides	Data not available	Low	Moderate	Data not available	Known to degrade in soil; rates and significance unknown
Phenoxy acids, esters, salts	Moderate	Low	Moderate to high	Low to moderate	Moderate to high (hydrolysis)
Organophosphorus compounds	Low	Low	Moderate to high	Moderate to high	Moderate to high

TABLE A-2. CHEMICAL PROPERTY RANGES THAT RELATE TO DEGREE OF SUSCEPTIBILITY TO MAJOR ENVIRONMENTAL (INTERMEDIA) TRANSPORT MECHANISMS[a]

Mechanism	Property	Range and Susceptibility		
		Low	Moderate	High
Adsorption to soil	Octanol/water Partitioning (K_{ow})	<2	2 to 4	>4
	Soil type[b]	Mineral	Clay	Organic Matter[c]
Leaching from/ through soil	Aqueous solubility	≤10 mg/l	1,000 mg/l	≥10,000 mg/l
Volatilization from soil	Vapor pressure	≤0.1 torr	1 torr	≥10 torr
	Henry's Law constant	$\leq 10^{-4}\ \frac{\text{atm-m}^3}{\text{mole}}$	10^{-3} to $10^{-2}\ \frac{\text{atm-m}^3}{\text{mole}}$	10^{-1} to $10^{0}\ \frac{\text{atm-m}^3}{\text{mole}}$

[a] Summary table for general guidance only; does not consider functional groups or multiple chemical properties.

[b] While not actually a chemical property of a hazardous constituent, the soil type is incuded here because it is highly significant to transport of a substance released to the soil medium.

[c] The soil organic matter content (low, medium, or high) relates to likelihood of adsorption based on K_{ow} predictions.

chlorinated solvents;
aliphatic and aromatic hydrocarbons;
acids;
bases;
detergents;
water; and
aqueous solutions of any of the above.

- Climatic Conditions - What are the typical climatic conditions for the region and how could they influence transport and fate?

    - Annual Rainfall - Rain could act as a dust supressant for soil-adsorbed hazardous constituents; in arid climates, generation of contaminated dust would be more likely. Rain could act as a solvent for soluble or slightly soluble compounds; infiltrating rain could leach hazardous constituents out of the soil and transport them to ground water. Surface run off from rainfall could mobilize contaminated particles and move the contaminated soil via overland flow.

    - Temperature - Volatilization will increase with increasing temperature. In hot weather, greater amounts of volatile and semivolatile hazardous constituents would migrate from soil into the vapor state.

    - Prevailing Wind Direction/Magnitude - Assessment of potential transport via fugitive dust requires knowledge of the magnitude and direction of prevailing winds. A wind rose, as required in the Part B permit application, provides data by which to evaluate transport of dust and to indicate where contaminated dusts would be most likely to be carried.

- Physical Characteristics of Release Location - Are there conditions in the release area that will influence transport and fate of the hazardous constituents?

    - Vegetative Cover - Plants growing in the area of the release can help reduce mobility of contaminated soils by affording protection from wind erosion or light traffic (foot) generation of dusts. Plant roots can hold soil so that channeling is minimized and surface runoff does not carry large amounts of contaminated soil from the release area.

    - Surface Drainage Patterns - Surface water (or runoff) flow patterns over the release area should be studied to determine whether runoff is moving into or out of the area. If significant runoff flows through the contaminated area, there is a greater chance of movement of the contaminated soils and also a greater chance of leaching of soluble or partially soluble compounds. Channeling or manmade drainage ditches in the area of the discharge are of special concern.

-- Saturated or Unsaturated Soils - The amount of moisture in the soil will influence whether constituents can volatilize through pore spacings or whether they will be hindered by an inability to dissolve in the aqueous phase. For soluble constituents, saturation can be a means of transport by leaching the hazardous constituents from soil. In moist, unsaturated soil, the soluble constituents may dissolve but remain associated with soil particles through the adsorption of water onto the particles.

- Human Activity - Do people utilize the area near the release in such a way as to enhance mobilization of the hazardous constituents? Are heavy equipment and other vehicles operated in the area capable of generating dust containing contaminated soils?

- Is the release to surface soil or the subsurface?

  - This question is important because releases to surface and subsurface soils present different risks of exposure and are subject to different transport mechanisms. A release to subsurface soils generally does not present a significant hazard from exposure to the soil itself; rather, hazardous constituents may move through the soil resulting in exposure via other media such as air (vapor transport through pore spacings) or ground water (dissolution in aqueous medium). Exposure to surface soil releases can be by direct contact, ingestion or inhalation of airborne particulate. This latter exposure could be caused by wind action on contaminated soil or by activity within the contaminated area causing dust to be generated.

- What types of soil are present in the area of the release?

  - The type of soil to which a hazardous constituent is released will strongly influence the transport of that constituent. For organic constituents, a parameter used to assess soil adsorption is the K_{ow}; this value has been correlated to adsorption on soil organic matter (Chiou, et al, 1979 and 1983). Therefore, the organic carbon content of the soil is significant in assessing transport. Because actual data are often not available, one can look at whether the release is to a subsoil (organic carbon content of 2 to 4 percent), topsoil (organic carbon content of 12 to 18 percent), or to a peat type soil (organic carbon content often greater than 50 percent). Additional soil type information relevant to assessing transport would be whether the soils were comprised of clay or mineral materials. Minerals would be expected to have a rather insignificant ability to adsorb organic or inorganic hazardous constituents and attenuate their movements. However, clay soils with their high surface area and frequently large number of ion exchange sites could be expected to adsorb both organic and inorganic constituents. Figure A-1 provides estimates (Forstner and Wittman, 1979) of bonding strength of several heavy metals (1) adsorbing onto and into clay lattice structures and (2) forming insoluble complexes with natural organic materials (humic substances).

Checklist for Assessment of Transport and Fate

A listing of the information discussed above is provided in Figure A-2 as a checklist for investigating releases to soil from SWMUs. The two major categories of information that are needed are physical and chemical characterization of the hazardous constituent release and characterization of the location of the release. Primary sources of this information are the facility's Part B permit application including the Exposure Information Report (EIR) and the Health Effects Assessments (HEAs) available from OERR. These must be supplemented by site specific information obtainable from a facility inspection and, as necessary, by chemical data from standard reference works.

Information on chemical composition of wastes handled at the SWMU at which the release occurred should be available in the Part B permit application. This will indicate the chemical compounds that may be expected in the release and may possibly indicate the physical form of the release (i.e., solid, liquid, sludge). Chemical information on the specific compounds released must be obtained from the HEAs supplemented as necessary by standard reference works.

Information on the location of the release must be obtained in part from the RCRA facility's (i.e. SWMUs) Part B permit application but with extensive input obtained during an onsite inspection and/or from interviews with facility personnel. Human activity patterns in the area of the release and the handling of potentially reactive wastes should be elucidated from information required in the Part B permit application and the EIR. Other relevant information that should be obtained from these same documents includes rainfall data, prevailing wind direction (wind rose), and surface runoff and drainage patterns. The EIR should also include information on site conditions that could substantially affect transport and fate (e.g. high water table, porous soils, etc.).

INORGANIC/CLAY INTERACTIONS

Empirical affinity series for ion exchange adsorption

Pb > Ni > Cu > Zn

Strength of incorporation into clay lattice structure

Strong: Cu, Fe, Ag

Moderate: Pb, Mn, Zn, Co

Weak: Cd

ORGANIC (HUMIC AND FULVIC) COMPLEXES

Bonding strength

$UO_2^{2+} > Hg^{2+} > Cu^{2+} > Pb^{2+} > Zn^{2+} > Ni^{2+} > Co^{2+}$

Complex stability series for soils

Pb > Cu > Ni > Co > Zn > Cd > Fe > Mn

Complex stability series for metal-humic substances

Strong: Cu, Sn, Pb

Moderate: Zn

Weak: Ca, Mg, Mn, alkali metals

Figure A-1. Metals Adsorption and Complex Formation.

A. TYPE OF HAZARDOUS CONSTITUENT RELEASED

1. Compound type or class

2. Functional groups present

3. Relevant chemical/physical properties

    a. Aqueous solubility
    b. Octanol/water partition coefficient
    c. Henry's Law Constant
    d. Vapor pressure
    e. Vapor density
    f. Other physical properties

4. Physical form of release

B. LOCATION OF RELEASE

1. Characteristics of the area

    a. Chemical activity (existing or potential release of other reactive chemicals)
    b. Climatic conditions
        (1) annual rainfall
        (2) temperature
        (3) wind rose
    c. Physical characteristics
        (1) vegetative cover
        (2) surface drainage patterns
        (3) saturated or unsaturated soils
    d. Human activity (potential soil disturbances)

2. Release to surface or subsurface soils

3. Soil types at release location

    a. Mineral
    b. Clay
    c. Organic matter content
        (1) low (subsoil, sandy soil)
        (2) medium (top soil, loamy soil)
        (3) high (peat)

Figure A-2. Checklist/Summary for Assessment of Potential Transport and Fate.

SUMMARY

Potential transport and fate of hazardous constituents released to the soil can be estimated by following the procedure that has been outlined in this appendix (Appendix A). The need for such an assessment is twofold. First, a determination of the transport pathways and migration potential of the hazardous constituent is necessary for one to identify potential exposures to nearby populations and environments.

Second, migration, persistence, and potential exposure can be used to assess the need for and effectiveness of proposed corrective actions. For soil releases and exposures to the soil medium, the transport pathways of concern include soil transport via surface runoff, fugitive dust, adsorption with immobilization on surface soils, and uptake by biota. If the hazardous constituents are expected to migrate to other media (e.g. volatilization to ambient air, dissolution in surface water or ground water), refer to the individual guidance documents for those media (GCA, 1985a; GCA, 1985b; E. C. Jordan, 1985). However, if the hazardous constituents remain in the soil medium and are expected to transport via the pathways listed above, one should consult the remainder of this guidance document. Appendix B provides information on conducting an exposure assessment for a hazardous constituent release to soil. It explains what constitutes an exposure assessment and what information is needed to conduct qualitative and quantitative exposure assessments. General procedures for hazard and risk assessment are also discussed in Appendix B.

APPENDIX B

EXPOSURE ASSESSMENT

INTRODUCTION

This section has been prepared consistent with the EPA guidance set forth in the following documents:

- Schultz, et al., Draft Superfund Exposure Assessment Manual, prepared for the U.S. EPA, Office of Toxic Substances, August 17, 1984.
- EPA, 1984c and EPA, 1985.
- ICF, Inc., Draft Superfund Health Assessment Manual, prepared for the U.S. EPA, Office of Emergency and Remedial Response, May 22, 1985.

Other sources of information used in preparation of this section are presented in the references section of this report.

Pending publication of guidance specific to RCRA enforcement, two of these documents (e.g. Schultz, et al., 1984; ICF, Inc., 1985) developed for use in assessment under CERCLA represent the best available information for assessment of public exposure (and risk) resulting from soil releases. Although these documents primarily concern human population exposure (and risk) assessment, they also provide the basis for evaluating exposure (and risk) to non-human populations.

The purpose of the exposure assessment is to determine all routes of exposure to human (and non-human) populations resulting from hazardous constituent releases to soil and other environmental media contaminated as a result of transport from the soil medium. Determination of whether or not exposure to humans (or other receptors) will occur at a source at-present or in the future typically involves determination of:

- the fate and transport of hazardous constituents to soil and other related environmental media through identification of likely pathways of constituent release and transport from identified sources, and,

- **human** (and non-human) populations at risk of exposure to hazardous constituents in soil and related environmental media through identification of activity patterns near the source or point of migration.

Appendix A provides guidelines for evaluating transport potential and fate of releases of hazardous constituents to soil. Appendix B will focus on evaluating exposure to human (and non-human) receptors from identified releases and will provide guidance on conducting exposure assessments.

The following six subsections of Appendix B describe the components necessary for exposure assessment, and provide guidance for the selection and performance of an appropriate exposure assessment methodology. The first subsection will concern exposure pathway analysis, and will provide guidance for identifying exposure pathways and determining whether pathways are complete. Determination of complete exposure pathways will establish the course of subsequent exposure analysis.

Subsection 2 will discuss the types and levels of exposure analysis for the permit writer to consider. Exposure assessments can be either qualitative or quantitative; however, regardless of the method or level of assessment employed, the outcome of the exposure analysis forms as a basis for characterizing risks to human health associated with exposure. Exposure assessments which are qualitative in nature are useful because they target key pathways and routes of human exposure, and therefore can be used to derive qualitative estimates of human risk associated with exposure. Exposure assessments which are quantitative in nature are useful because they also identify significant pathways and routes of human (and non-human) exposure, and quantify actual human intake, thus establishing baseline conditions for quantitative risk assessment.

Subsection 3 will discuss the rationale for selecting and performing qualitative or quantitative exposure analysis. Informational requirements for each level of analysis will be described in detail to assist the permit writer in selecting the most appropriate method.

Subsections 4 and 5 will describe in detail the necessary steps for performing qualitative and quantitative exposure analysis, respectively. Uses of exposure information from these various levels of assessment (e.g. qualitative or quantitative) will also be discussed in these sections. In particular, guidance will be provided to assist the permit writer in utilizing derived exposure information for two purposes:

- to determine the level and means of corrective actions necessary to adequately reduce human exposure (and risk) associated with identified release of hazardous constituents to soil, and
- to provide an approach for evaluating public health impacts associated with such releases to soils.

The sixth and final subsection will describe the risk characterization process. Guidance will be provided to assist the permit writer in characterizing risks to human (and non-human) populations associated with exposure to hazardous constituents. Methodologies, informational requirements, and limitations of risk characterization processes will also be considered.

PATHWAY DETERMINATION

Assessment of exposure to human (and non-human) populations (e.g. receptors) proceeds directly from identification of complete exposure pathways. A complete exposure pathway has the following four necessary components: (1) a source of chemical release into the environment, (2) an environmental transport medium (e.g. air, surface water) for the released chemical, (3) a potential exposure point, and (4) a human (or non-human) exposure route at the contact point. Identification of exposure pathways establishes the course of subsequent exposure analysis. Thus, the permit writer should focus on identifying exposure pathways and determine whether the pathway is complete. Pathways which are complete (e.g. where a release, movement of hazardous constituents through environmental media, and likelihood of human or non-human exposure are all evidenced), will require exposure characterization so as to qualify or quantify the magnitude, frequency, and duration of human exposure to contaminated media. Pathways which are not complete will, in most instances, be eliminated from further analysis, or may identify existing data gaps which must be filled in order to assess more conclusively the potential for and impact of human exposure via those pathways. Guidance for determining potential exposure pathways is provided in Table B-1. For further guidance in the determination and evaluation of potential exposure pathways, the reader is referred to ICF, Inc., 1985.

LEVELS OF EXPOSURE ASSESSMENT

Depending on the available information and the permit writer's need, varying levels of exposure assessment can be performed. Basically, exposure assessments can be either qualitative or quantitative. Assessments which are qualitative are referred to as level I analyses, while those which are quantitative are referred to as level II (or level III) analyses. In general, a level I analysis is a qualitative evaluation which provides a preliminary screening of on-site hazardous constituent release sources, environmental pathways through which constituents migrate off-site, and possible human (and non-human) population exposure points and mechanisms. A level I analysis gives an indication of the nature and extent of public health threats resulting from exposure to a hazardous constutuent source. Level II (quantitative) analyses develop estimates of the quantities of the release (e.g. mass loading) of chemicals of concern from sources identified in level I, and considering hazardous constituent transport and enviromental fate, estimate the degree of potential population exposure (and risk) resulting from exposure. Level II exposure analyses also allow for estimation of intake (or dose) incurred by human (and non-human) receptors. A further refinement of a level II analysis is also possible given the degree of sophistication of existing data. This very detailed analysis is referred to as a level III assessment. In level III assessments, those key hazardous constituent release and exposure scenarios targeted in level II are quantitatively analysed in detail. It is basically an indepth level II analysis, although the analytical tools necessary for the analysis are more resource intensive than those required for level II analysis, and the results are of significantly greater

Name of Source:
Date:
Analyst:
QC:

TABLE B-1. POTENTIAL EXPOSURE PATHWAY DETERMINATION

	Release Source/Mechanism	Release Medium	Exposure Point	Exposure Route
1.	Contaminated surface soil	air media	nearby playground	inhalation (possible reingestion
2.				
3.				

INSTRUCTIONS

1. List release source.
2. List release medium.
3. Describe the nature of the exposure point.
4. List exposure route: e.g. ingestion, inhalation, dermal contact, including possible indirect routes, such as uptake by biota and subsequent ingestion by humans.

ASSUMPTIONS

List all major assumptions in developing the data for this worksheet:

Source: ICF, Inc., 1985.

accuracy (e.g. computer modeling or environmental monitoring). The characteristics of each level of analysis are briefly summarized in Table B-2 (Schultz, et al., 1984).

CRITERIA FOR SELECTING THE LEVEL OF ASSESSMENT

The determination of which level of assessment is appropriate for evaluation of a hazardous constituent release to soils (or other environmental media) will ultimately be a judgement decision by the permit writer; however, the selection should be based on criteria associated with the baseline conditions of the hazardous constituent source. These criteria concern: (1) conditions at and around the source, (2) the level of detail needed in the analysis, and (3) the ultimate intended use of the exposure analysis (e.g. to establish permit conditions, determine corrective measures, etc.). Table B-3 shows how these criteria can be used to determine the level of exposure and risk assessment appropriate for evaluation of a source of hazardous constituent release to soils. In order to define conditions at and around the facility, the permit writer must have available the following information:

- source background data;
- disposal history (and records, if available);
- chemical analysis data for locations at and near the source;
- source characterization data (e.g. topography, hydrogeology);
- information on local human population;
- any human body burden and health effects data (unlikely to be available for most sources); and
- types of corrective measures considered.

The primary sources for this information are RCRA Part B Applications, site inspections, and analytical data and reports available from past or ongoing facility characterization. Depending on the level of need of the permit writer, data used to evaluate baseline conditions at and around the source can be used to determine what corrective measures, if any, should be

TABLE B-2. CHARACTERISTICS OF EXPOSURE ASSESSMENT ANALYTICAL LEVELS

Analytical Level	Nature of Analysis	Level of Detail	Characteristic Analytical Tools	Resource Intensiveness
Level I	Qualitative: Broad Scale Screeing	Low	Decision Networks	Low
Level II	Quantitative: Minimal targeting	Moderate	Simple Estimation Equations	Moderate
Level III	Quantitative: Highly targeted	High	Computer Modeling; Monitoring	High

Source: Schultz et. al., 1984.

TABLE B-3. CRITERIA FOR DETERMINING LEVEL OF EXPOSURE (AND RISK) ASSESSMENT APPROPRIATE FOR EVALUATING A RELEASE OF HAZARDOUS CONSTITUENTS TO SOIL

	Level of Assessment Necessitated	
Criteria	Level I	Level II (or Level III)
(1) Conditions at the facility	-contamination is confined to and migrated little from the facility, and direct contact by human populations is unlikely.	-the quantity, frequency, and potential toxicity of an observed release indicates migration from the facility into a transport medium (e.g. out, surface water). -if exposures have already occurred or are imminent
(2) Conditions around the facility	-topographical and geological data indicate that releases would travel very slowly in environmental media, and no large or sensitive populations are located near the facility	-topographical and geological data indicate that releases would travel at moderate or rapid rates in environmental media -presence of a large population near facility (despite limited migration potential of hazardous constituents from the facility)
(3) Level of need	-the exposure assessment need not be rigorous because the qualitative evaluation will be used to determine what corrective actions, if any, will be taken at the source, or will be utilized to establish relative degrees of hazardous contaminant release to soils which are considered acceptable. Reliable sources: e.g., analytical data, time, money, expertise, warrant a Level I analysis substantial.	-the exposure assessment will be used, or is likely to be used to determine what corrective actions, if any, will be taken at a source, or to establish acceptable levels of releases to soil in the absence of existing standards. Available resources: e.g. analytical time, money, expertise warrant a Level II analysis necessary.

Source: ICF, Inc., 1985.

taken at the source, or in the case of post-remediation, to evaluate the efficacy of the chosen corrective measure at reducing releases of hazardous constituents to an acceptable (target) level.

The initial decision as to which level of assessment is to be performed at a source should be preliminarily determined (if possible) during initial review of the baseline facility data. At this time, the extent of chemical contamination at the source can be estimated, and based on existing conditions at the facility and affected (e.g. exposed) population profiles, a decision on the appropriate level of exposure (and risk) assessment can be made. Initial selection of level I or level II, however, is not necessarily final. As the exposure assessment proceeds it may become clear that the initial level of analysis chosen is not appropriate when considering all available data. At that point, the level of analysis may change. At the time of initial decision of the level of detail required existing gaps in the quality and quantity of available data should also be identified. If necessary, measures can be taken to obtain information necessary for adequate exposure evaluation. For example, should the permit writer, after review of a facility's Part B Application, determine that a level II analysis is required but not possible given available information requests for additional information to perform the more detailed analysis can be specified.

QUALITATIVE ASSESSMENT OF EXPOSURE

The key element of the qualitative (level I) exposure assessment is a comprehensive exposure pathway analysis, in which potential pathways are indentified and characterized. The assessment involves preliminary determination of complete exposure pathways by performing three analysis steps. These include:

- hazardous consittuent release characterization and analysis,
- environmental fate analysis (e.g., identification of environmental pathways through which hazardous constituents migrate from the source), and
- exposed population analysis (e.g., identification of possible human and non-human exposure points and mechanisms).

The level I exposure evaluation can have a wide range of detail, although the extent to which hazardous constituent releases can be quantified is dependent on previously gathered analytical data. No new analytical data, or quantification, is generally required. Therefore, calculation of human doses (at identified receptor points) cannot be conducted.

Once a hazardous constituent release to soils has been identified, the permit writer can effectively perform a level I analysis by utilizing a series of decision networks for each of the three exposure pathway analysis steps cited above (i.e., hazardous constituent release, environmental transport and fate, and exposure point and route analysis). The decision networks provide a framework for performing each exposure analysis step via a series of questions relevant to the analysis process. The answers to these questions provide information which can serve in determination of the following:

- existing exposure pathways (e.g., release/transport/human exposure pathways) which are complete. Those exposure pathways which are incomplete may be eliminated from further analysis, unless subsequent data are obtained which modifies conclusions drawn from existing analytical data.

- the relative magnitude (e.g. low, moderate, high significance) of exposure pathways associated with hazardous constituent release at the facility. This can be used to target those pathways for which more in-depth (level II) analysis is required versus those pathways which appear of more minor significance or which can be adequately characterized by level I analysis.

- existing gaps in the (quantity and quality of) available analytical data. This can be used to develop strategies for acquiring additional data in order to conduct quantitative (level II or III) analyses if they are warranted.

- corrective measures which may be applicable for implementation at the facility.

The three basic steps in performing a level I (qualitative) exposure assessment include analysis of: (1) the source of hazardous constituent release; (2) environmental transport and fate; and (3) potentially exposed populations. The following subsections describe these three steps of the qualitative analysis process, and provide as guidance the decision networks with which they can be effectively evaluated. The qualitative exposure analysis is a stepwise process; e.g., the output of each step in the exposure analysis process serves as input to and provides direction for the following step. Therefore, the output of the hazardous constituent release analysis serves as the input for the environmental fate analysis, which in turn, serves as input for the exposed population analysis.

Hazardous Constituent Release Analysis

Based on available information from site inspections, analytical data and reports available from past or ongoing source investigations, and RCRA Part B Applications, the nature and magnitude of releases to soils from hazardous constituent sources can be determined. Data obtainable from these sources relevant to release characterization include:

- chemical/physical properties of the hazardous constituents;
- climatological regime of the area; and
- the location and manner of placement at the facility (e.g. buried in landfill, present in surface lagoon).

Depending on the location of hazardous constituents and manner of waste disposal, hazardous constituent release from a source may occur via any or all of the following mechanisms:

- Source leaching;
- Surface runoff;
- Episodic overland flows;
- Fugitive dust generation/deposition; and
- Tracking.

The procedure for characterizing the nature and probable significance of release (e.g., environmental loading) can be faciliated by means of a decision network, as shown in Figure B-1. The output of this analysis, in turn, is used as input to the second step in the evaluation process, environmental fate analysis.

Environmental Fate Analysis

Analysis of the environmental transport and fate of hazardous constituents released to the soil medium involves determination of two inputs: (1) the

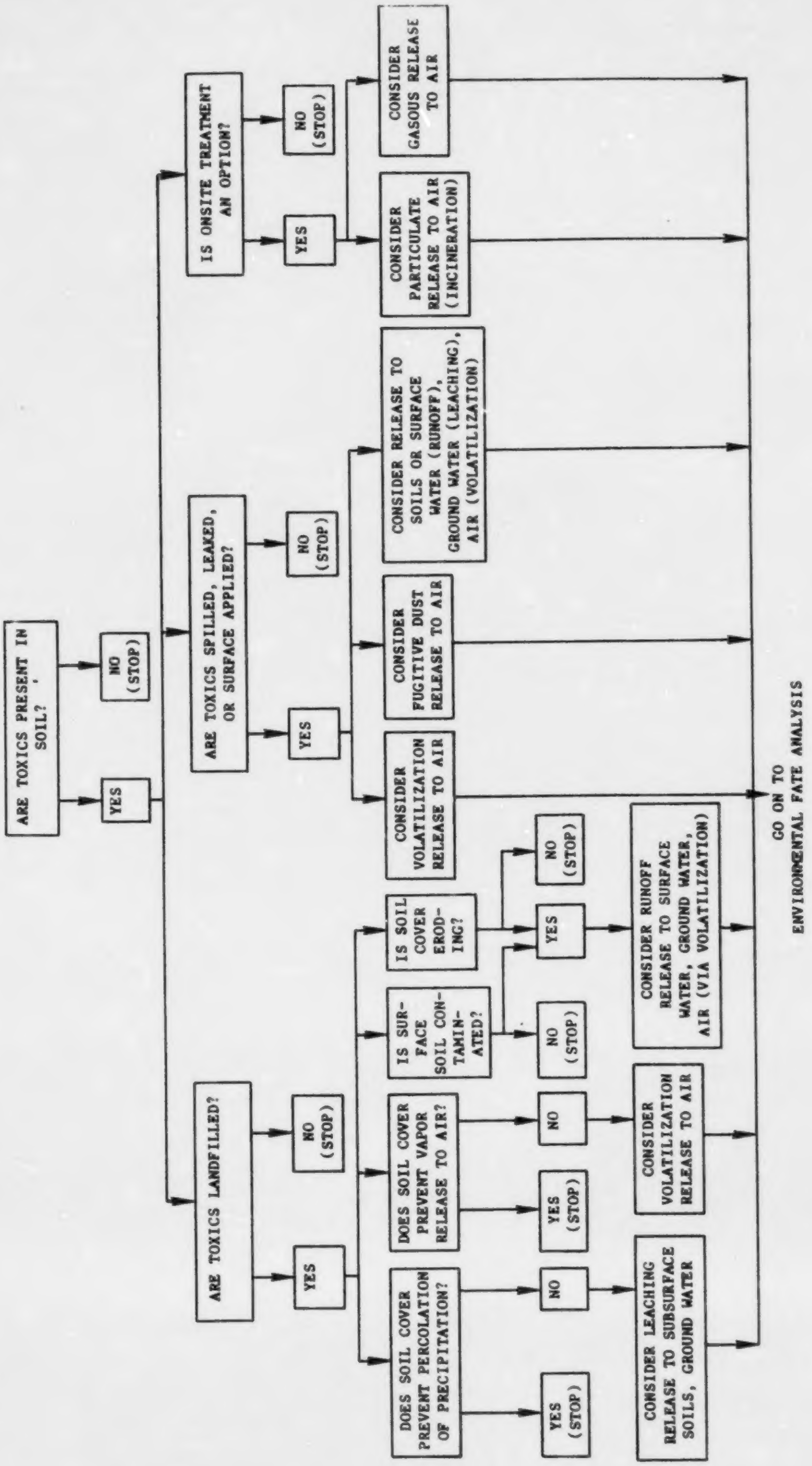

ARE TOXICS PRESENT IN SOIL?
YES
NO (STOP)
ARE TOXICS LANDFILLED?
YES
NO (STOP)
DOES SOIL COVER PREVENT PERCOLATION OF PRECIPITATION?
YES (STOP)
NO
CONSIDER LEACHING RELEASE TO SUBSURFACE SOILS, GROUND WATER
DOES SOIL COVER PREVENT VAPOR RELEASE TO AIR?
YES (STOP)
NO
CONSIDER VOLATILIZATION RELEASE TO AIR
IS SURFACE SOIL CONTAMINATED?
NO (STOP)
IS SOIL COVER ERODING?
YES
NO (STOP)
CONSIDER RUNOFF RELEASE TO SURFACE WATER, GROUND WATER, AIR (VIA VOLATILIZATION)
ARE TOXICS SPILLED, LEAKED, OR SURFACE APPLIED?
YES
NO (STOP)
CONSIDER VOLATILIZATION RELEASE TO AIR
CONSIDER FUGITIVE DUST RELEASE TO AIR
CONSIDER RELEASE TO SOILS OR SURFACE WATER (RUNOFF), GROUND WATER (LEACHING), AIR (VOLATILIZATION)
IS ONSITE TREATMENT AN OPTION?
YES
NO (STOP)
CONSIDER PARTICULATE RELEASE TO AIR (INCINERATION)
CONSIDER GASOUS RELEASE TO AIR
GO ON TO ENVIRONMENTAL FATE ANALYSIS

Figure B-1. Release decision network: Hazardous constituents.

Source: Schultz, et. al., 1984.

extent (e.g. magnitude) of release to soil, and (2) the potential for migration in environmental media. Both intermedia transport mechanisms (e.g. adsorbtion and/or entrainment in air, and bioaccumulation) and intramedia transformation processes (e.g. photolysis, oxidation, hydrolysis, and biodegradation) are qualitatively considered during this second step. The evaluation will be based on results of the hazardous constituent release analysis. Information required for the environmental fate analysis is similiar to that of the previous section, including:

- physical/chemical properties of the hazardous constituents;
- manner of placement or disposal; and
- relevant climatological, hydrogeological source condition information.

The outcome of the qualitative environmental fate analysis is a determination of the likely extent of release to the environment from the facility (e.g., environmental loading). The nature of the hazardous constituents involved and probable magnitude of their release are also considered. When the outcome of this analysis is integrated with information concerning populations affected by the source, subsequent evaluation of potentially exposed human populations can be performed. Because the environmental fate analysis is such an integral part of the exposed population analysis, decision networks used to evaluate the former are more appropriately considered in the latter section, exposed population analysis.

Exposed Population Analysis

The third step in performing a qualitative exposure assessment is the exposed population analysis. Analysis of potentially exposed human (and non-human) populations involves determination of the likely routes and extent of population exposure to contaminants released to soils. It also considers the duration of expected exposure (e.g., either short-term or long-term). The exposed population analysis is the final step in identification of those exposure pathways which are complete, and thereby completes the level I qualitative assessment; it also serves as a basis for planning and conducting subsequent quantitative (e.g., level II and III) assessments. By determining the magnitude of probable exposure via pathways identified, those pathways which are considered to be of major significance may require level II (and/or level III) analysis, while those which are considered of minor significance or can be easily characterized may be adequately evaluated by the level II analysis. The analysis is straightforward and involves identification of two inputs:

(1) the land use and activity patterns of human populations near the source; and

(2) the areas of potential human exposure to hazardous constituents released to soils (as identified in Step 2, the environmental fate analysis).

The exposed population analysis can be performed via several decision networks, one for each of the transport mediums identified in the previous step, environmental fate analysis. Decision networks for those transport media of concern (when considering release of hazardous constituents to soil) are presented below. In essence, the decision networks are frameworks for the environmental-fate-and-exposed-population analysis because they combine the information derived from the envionmental fate analysis with the projected likelihood of population exposure to contaminated areas (as identified by human activity and land use patterns near the facility). They provide a qualitative estimate of the relative magnitude of human exposure (and risk) via identified exposure pathways and routes. The duration of expected exposure is also determined at this step in the exposure analysis. Guidance for determination of exposure duration is based on baseline conditions of contamination at the facility, and can be summarized by the criteria shown in Table B-4.

When considering releases of hazardous consituents to soil, several routes of human (and non-human) exposure should be evaluated, including:

- direct contact with soils;
- inhalation of airborne particulates to which contamination is adsorbed, with possible reingestion of particulates;

TABLE B-4. DETERMINATION OF EXPOSURE DURATION: A CONSIDERATION OF BASELINE FACILITY CONDITIONS

CRITERIA TO CONSIDER REGARDING BASELINE FACILITY CONDITIONS:

1. Access to the facility or areas contaminated as a result of migration from the facility: Is the facility:

   - accessible to,
   - restricted (e.g. by a fence or physical source conditions) from, or
   - otherwise unaccessed (e.g. due to great distance) by human populations?

   a. If restricted, to what extent? (e.g. the presence of a fence is not sufficient indication that access is prevented).

2. Are there natural manmade features of the source or surrounding area such as:

   - abondoned buildings,
   - standing water or streams

   which may attract people, in particular children?

3. Are there human use areas, such as:

   - playgrounds
   - schools
   - parks

   located near the facility which may be frequently utilized by people, in particular children, despite efforts to restrict access to the area?

- ingestion of soils (e.g., by a child exhibiting pica); and
- ingestion of food products into which hazardous constituents in soil have been uptaken.

Assessment of exposure to humans (and non-humans) via ingestion of food products and inhalation of airborne particulates (with possible reingestion) involves consideration of intermedia transport (e.g., to air or into biota) of hazardous constituents originally released to soils. These routes of exposure can be evaluated via the environmental-fate-and-exposed-population networks shown in Figures B-2 and B-3. Assessment of exposure via direct contact or ingestion of soils (e.g., by a child exhibiting pica, an abnormal craving for non-food items) can be performed at any hazardous constituent exposure point because the release/transport/and human exposure media are the same (e.g., soil) because no intermedia transport is involved.

Once the permit writer has performed the 3 steps of the qualtitative exposure analysis (e.g., release, transport, and exposed population analysis), he has determined which exposure pathways are complete, and has thus set the conditions necessary for characterizing risk (associated with exposure). Depending on the level of need, available resources (e.g., available source monitoring data), and projected significance of exposure (and risk), complete exposure pathways may be used as a basis for qualitatively evaluating risk associated exposure via those pathways and routes, or may be further evaluated by quantitative exposure analysis (e.g., level II or III), after which quantitative risk characterization will be performed. For instance, if the permit writer wishes to perform the exposure assessment to determine the relative significance (e.g., low, moderate, high) of exposure via identified routes and does not require in-depth (e.g., quantitative) assessment of exposure, then level I exposure analysis will be sufficient. If, on the other hand, the permit writer does desire in-depth exposure analysis (e.g., because the release is obviously significant or he wishes to plan corrective measures to eliminate exposure to a defined level), then level II analysis will be required. He will not be able to perform the level II analysis, however, unless sufficient environmental monitoring data are available.

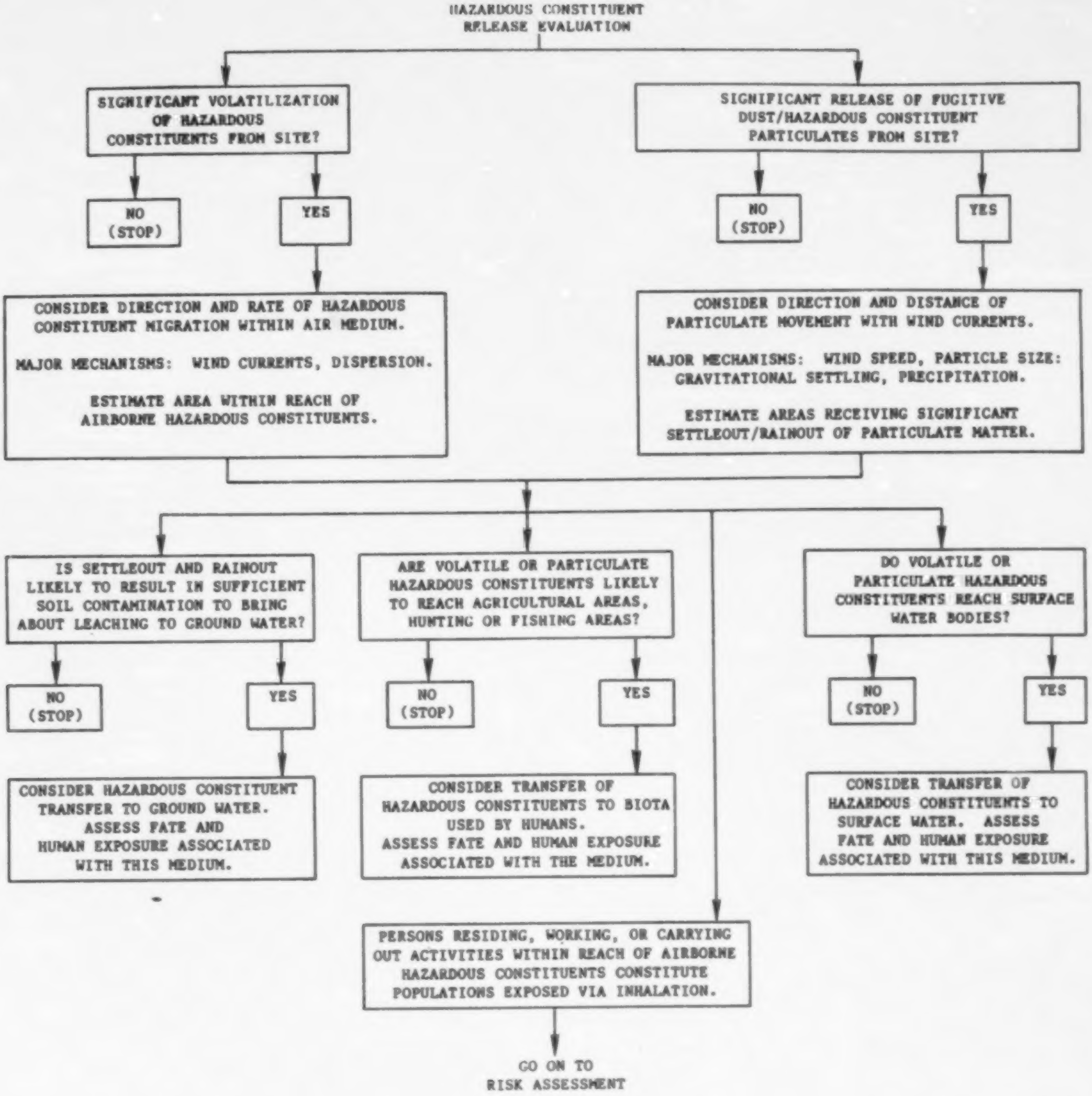

HAZARDOUS CONSTITUENT RELEASE EVALUATION
SIGNIFICANT VOLATILIZATION OF HAZARDOUS CONSTITUENTS FROM SITE?
NO (STOP)
YES
CONSIDER DIRECTION AND RATE OF HAZARDOUS CONSTITUENT MIGRATION WITHIN AIR MEDIUM.
MAJOR MECHANISMS: WIND CURRENTS, DISPERSION.
ESTIMATE AREA WITHIN REACH OF AIRBORNE HAZARDOUS CONSTITUENTS.
SIGNIFICANT RELEASE OF FUGITIVE DUST/HAZARDOUS CONSTITUENT PARTICULATES FROM SITE?
NO (STOP)
YES
CONSIDER DIRECTION AND DISTANCE OF PARTICULATE MOVEMENT WITH WIND CURRENTS.
MAJOR MECHANISMS: WIND SPEED, PARTICLE SIZE: GRAVITATIONAL SETTLING, PRECIPITATION.
ESTIMATE AREAS RECEIVING SIGNIFICANT SETTLEOUT/RAINOUT OF PARTICULATE MATTER.
IS SETTLEOUT AND RAINOUT LIKELY TO RESULT IN SUFFICIENT SOIL CONTAMINATION TO BRING ABOUT LEACHING TO GROUND WATER?
NO (STOP)
YES
CONSIDER HAZARDOUS CONSTITUENT TRANSFER TO GROUND WATER. ASSESS FATE AND HUMAN EXPOSURE ASSOCIATED WITH THIS MEDIUM.
ARE VOLATILE OR PARTICULATE HAZARDOUS CONSTITUENTS LIKELY TO REACH AGRICULTURAL AREAS, HUNTING OR FISHING AREAS?
NO (STOP)
YES
CONSIDER TRANSFER OF HAZARDOUS CONSTITUENTS TO BIOTA USED BY HUMANS. ASSESS FATE AND HUMAN EXPOSURE ASSOCIATED WITH THE MEDIUM.
DO VOLATILE OR PARTICULATE HAZARDOUS CONSTITUENTS REACH SURFACE WATER BODIES?
NO (STOP)
YES
CONSIDER TRANSFER OF HAZARDOUS CONSTITUENTS TO SURFACE WATER. ASSESS FATE AND HUMAN EXPOSURE ASSOCIATED WITH THIS MEDIUM.
PERSONS RESIDING, WORKING, OR CARRYING OUT ACTIVITIES WITHIN REACH OF AIRBORNE HAZARDOUS CONSTITUENTS CONSTITUTE POPULATIONS EXPOSED VIA INHALATION.
GO ON TO RISK ASSESSMENT

Figure B-2. Environmental fate and human exposure analysis decision network: Hazardous constituents in air.

Source: Schultz, et al., 1984.

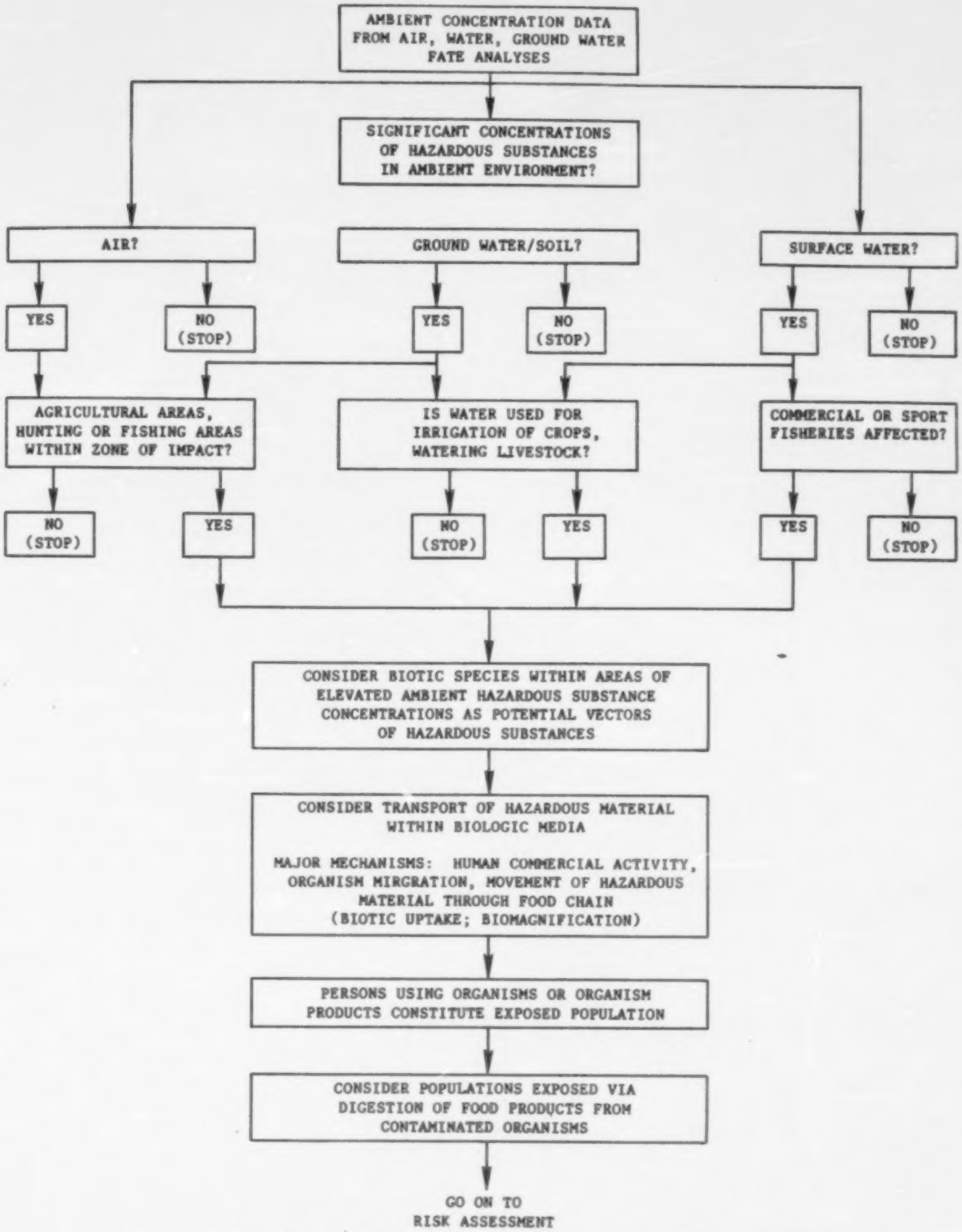

AMBIENT CONCENTRATION DATA FROM AIR, WATER, GROUND WATER FATE ANALYSES
SIGNIFICANT CONCENTRATIONS OF HAZARDOUS SUBSTANCES IN AMBIENT ENVIRONMENT?
AIR?
GROUND WATER/SOIL?
SURFACE WATER?
YES
NO (STOP)
YES
NO (STOP)
YES
NO (STOP)
AGRICULTURAL AREAS, HUNTING OR FISHING AREAS WITHIN ZONE OF IMPACT?
IS WATER USED FOR IRRIGATION OF CROPS, WATERING LIVESTOCK?
COMMERCIAL OR SPORT FISHERIES AFFECTED?
NO (STOP)
YES
NO (STOP)
YES
YES
NO (STOP)
CONSIDER BIOTIC SPECIES WITHIN AREAS OF ELEVATED AMBIENT HAZARDOUS SUBSTANCE CONCENTRATIONS AS POTENTIAL VECTORS OF HAZARDOUS SUBSTANCES
CONSIDER TRANSPORT OF HAZARDOUS MATERIAL WITHIN BIOLOGIC MEDIA
MAJOR MECHANISMS: HUMAN COMMERCIAL ACTIVITY, ORGANISM MIRGRATION, MOVEMENT OF HAZARDOUS MATERIAL THROUGH FOOD CHAIN (BIOTIC UPTAKE; BIOMAGNIFICATION)
PERSONS USING ORGANISMS OR ORGANISM PRODUCTS CONSTITUTE EXPOSED POPULATION
CONSIDER POPULATIONS EXPOSED VIA DIGESTION OF FOOD PRODUCTS FROM CONTAMINATED ORGANISMS
GO ON TO RISK ASSESSMENT

Figure B-3. Environmental fate and human exposure analysis decision network: food chain.

Source: Schultz, et al., 1984.

QUANTITATIVE ASSESSMENT OF EXPOSURE

The initial step of a quantitative exposure analysis is an evaluation of available source data to determine their completeness and adequacy, and to identify existing data gaps which must be filled prior to performance of the analysis. Once requisite data are acquired, quantitative evaluation of human (and non-human) exposure (either as a level II or III analysis) can proceed via the framework shown in Figures B-4. The first three steps of the quantitative exposure analysis process are similiar to those for the qualitative (e.g., level I) analysis process, and include:

- hazardous constituent release analysis;
- environmental fate analysis; and
- analysis of population exposure points and routes.

Unlike the qualitative exposure analysis process where each step in the analysis is qualitatively evaluated, each step of the quantitative exposure analysis process is quantitatively evaluated. Because level II (and III) assessments are quantitative in nature, they allow for determination of hazardous constituent intake or dose incurred by human receptors at identified exposure points. Determination of human intake or dose is performed subsequent to the three analyses cited above, and combines the output of each of the analysis steps. The goal of the level II (and level III) exposure assessment is the development of quantitative determinations of both individual risk and risk to exposed populations, which are preferably expressed as average versus maximum projected exposure (e.g., intake or dose). Because the quantitative exposure (and risk) assessment is performed by a series of analysis steps (e.g., release/transport/exposed population analysis), all of these steps must be quantitatively defined; e.g., the output of the release analysis must be expressed in terms of average and maximum release values, the output of the environmental fate analysis must predict average and maximum hazardous constituent concentrations in environmental media, and average and maximum population exposures must be determined by the extent to which the general population comes into contact with the average and

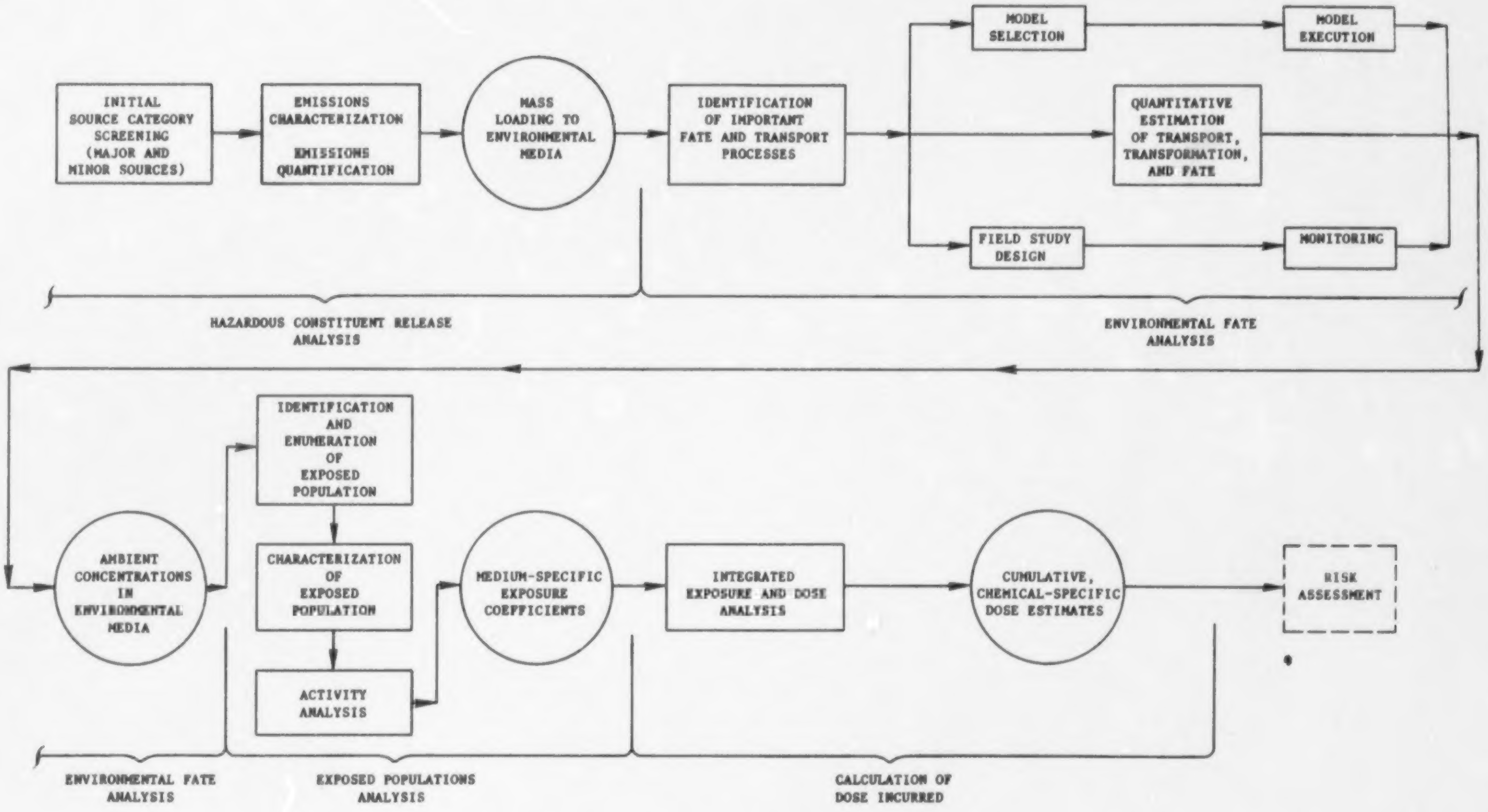

INITIAL SOURCE CATEGORY SCREENING (MAJOR AND MINOR SOURCES)
EMISSIONS CHARACTERIZATION EMISSIONS QUANTIFICATION
MASS LOADING TO ENVIRONMENTAL MEDIA
IDENTIFICATION OF IMPORTANT FATE AND TRANSPORT PROCESSES
MODEL SELECTION
MODEL EXECUTION
QUANTITATIVE ESTIMATION OF TRANSPORT, TRANSFORMATION, AND FATE
FIELD STUDY DESIGN
MONITORING
HAZARDOUS CONSTITUENT RELEASE ANALYSIS
ENVIRONMENTAL FATE ANALYSIS
IDENTIFICATION AND ENUMERATION OF EXPOSED POPULATION
AMBIENT CONCENTRATIONS IN ENVIRONMENTAL MEDIA
CHARACTERIZATION OF EXPOSED POPULATION
ACTIVITY ANALYSIS
MEDIUM-SPECIFIC EXPOSURE COEFFICIENTS
INTEGRATED EXPOSURE AND DOSE ANALYSIS
CUMULATIVE, CHEMICAL-SPECIFIC DOSE ESTIMATES
RISK ASSESSMENT
ENVIRONMENTAL FATE ANALYSIS
EXPOSED POPULATIONS ANALYSIS
CALCULATION OF DOSE INCURRED

Figure B-4. Overview of integrated exposure assessment process.

Source: Schultz, et. al., 1984.

maximum environmental concentrations. The last step of the quantitative exposure analysis, (e.g. quantification of human intake or dose) is then considered in conjuction with toxicological data for hazardous constituents of concern, and serves as the baseline risk assessment. The use of exposure information to characterize risk will be further discussed in this section.

For those sources, pathways, and routes of exposure evaluated in the level II analysis which are determined to be of minor significance and/or are sufficiently characterized (e.g., as determined by need), the level II analysis alone is sufficient. However, for those sources, pathways, or receptors which are of great magnitude or sensitivity (and available data and level of need permit), additional level III analysis may be performed. The primary distinctions between level II and level III quantitative analyses are shown in Table B-2. In brief, they concern four characteristics, including:

(1) The nature of the analysis: e.g. both levels II and III are quantitative, although level II requires minimal determination of significance, and level III intense determination of significance of exposure pathways and routes,

(2) Level of detail: level II are moderately and level III are highly detailed analyses,

(3) Characteristic analytical tools required: level II involves simple estimation equations, while level III requires either computer modeling or environmental monitoring to quantify hazardous constituent releases, environmental transport, and exposure point concentrations, and

(4) Resource intensiveness: the level II is moderately and the level III is highly resource-intensive.

The permit writer may perform either a level II or III analysis, depending on the quality of available data and degree of detail needed. A description of the use and methodology for performing both level II and level III analyses will therefore be discussed in the subsequent subsections.

There are 3 basic steps in performing quantitative (level II or III) exposure analysis. They include:

(1) hazardous constituent release analysis,

(2) environmental fate analysis, and

(3) exposed population analysis.

Utilizing the output from each of these three steps, the exposure analysis enables the permit writer to quantify human exposure (e.g., as intake or dose). Informational requirements and guidelines for performing the three basic steps of the quantitative exposure analysis and for quantifying human exposure (as intake or dose) are presented below. If additional information is desired, the reader is referred to sources cited below.

Quantitative Hazardous Constituent Release Analysis

The first step of the quantitative exposure analysis is the quantitative hazardous constituent release analysis. Quantitative analysis of releases of hazardous constituents to soils utilizes the results of the qualitative analysis performed at level I; e.g., the source of release identified in the level I analysis I is re-analysed at the level II and the release rate (e.g., mass release per unit time) is quantified. The output of the analysis is a measure of the mass loading of the hazardous constituents to the soil medium as well as to other media contaminated as a result of intermedia transport. The output of the analysis, in turn, serves as input for the second step of the exposure analysis, quantitative environmental fate analysis. A flow chart depicting the nesessary decision criteria for quantitative hazardous constituent release analysis (level II and III) is shown in Figure B-5.

Both level II and III assessments yield quantitative estimates of releases to soils based on hazardous constituent-and-site-specific factors. These estimates represent levels of environmental hazardous constituents to which human (and non-human) populations could potentially be exposed, either directly at the source or at points of hazardous constituent migration (e.g., as determined in subsequent analysis steps 2 and 3, environmental fate analysis and exposed population analysis). Quantification of hazardous constituent levels at this initial step of the exposure/risk analysis process is therefore fundamental to obtaining quantitative estimates of human exposure (e.g., intake or dose) as the final output to the quantitative exposure analysis process.

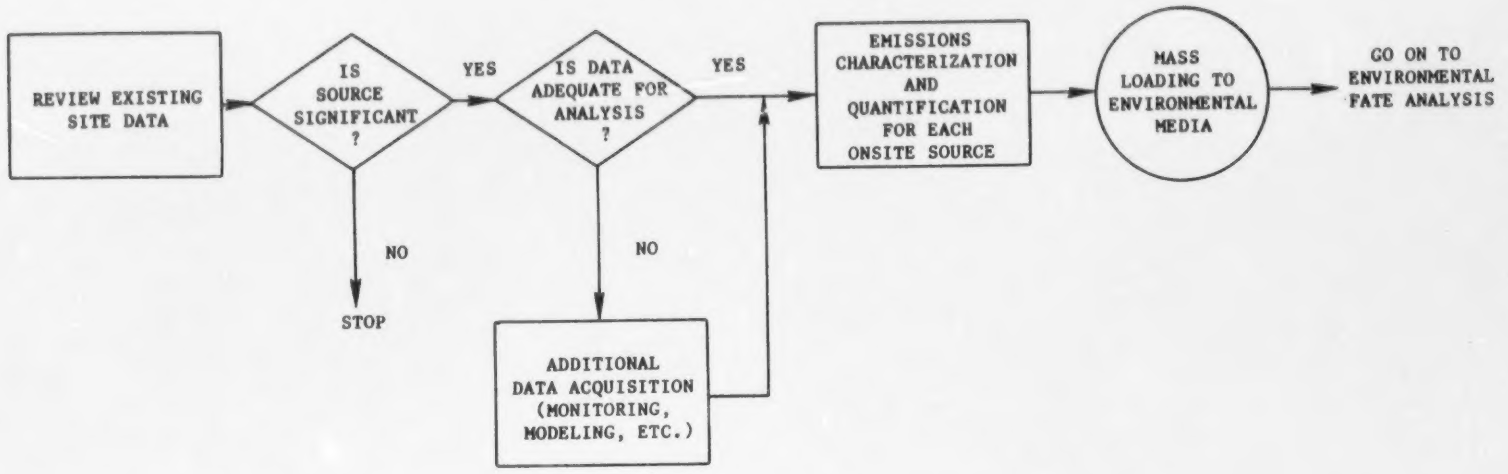

REVIEW EXISTING SITE DATA
IS SOURCE SIGNIFICANT ?
YES
NO
STOP
IS DATA ADEQUATE FOR ANALYSIS ?
YES
NO
ADDITIONAL DATA ACQUISITION (MONITORING, MODELING, ETC.)
EMISSIONS CHARACTERIZATION AND QUANTIFICATION FOR EACH ONSITE SOURCE
MASS LOADING TO ENVIRONMENTAL MEDIA
GO ON TO ENVIRONMENTAL FATE ANALYSIS

Figure B-5. Quantitative hazardous constituent release analysis (Levels II and III).

Source: Schultz, et al., 1984.

Quantitative release analyses (either at level II or level III) are expressed as release rates (e.g. mass release per unit time). Various methods are available for estimating release rates of hazardous constituents to environmental media from a variety of sources. Each release medium (e.g. soil, air) must be addressed separately; however, intermedia release of hazardous constituents must also be considered. In the case of releases of hazardous constituents to soils, there is one primary and two secondary release media of concern. They include:

- soil (as a primary release medium),
- air (as a secondary release medium, via entrainment of airborne particulates to which hazardous constituents have adsorbed), and
- biota (as a secondary and indirect release medium, via plant uptake of hazardous constituents adsorbed to or otherwise associated with soils).

Methods available for level II and III quantitative analysis of release to soils are referenced in Table B-5. Quantitative methods of release analysis to air (e.g., as a secondary environmental release medium) are also referenced in the table. Uptake by biota, (e.g., as a secondary, indirect release medium) can be evaluated by consideration of release to soils, since plant uptake occurs directly from the soil medium. The limitations and assumptions inherent in performing quantitative level II and level III contaminant release analyses are presented below.

Assumptions/Limitations of Level II Hazardous Constituent Release Analysis--

Procedures available for calculating environmental release estimates can be limited in that they: (1) often do not take into account the full range of variables which affect source release (e.g., hazardous constituent-specific and site-specific factors), and (2) often assume steady state conditions (e.g., do not address reduction in levels of hazardous constituents present due to release losses, and the associated reduction in release loading over time, corresponding to the decreased reservoir of hazardous constituents). Given these constraints, the quantitative release analysis is not expected to

TABLE B-5. METHODS AVAILABLE FOR LEVEL II AND LEVEL III ANALYSIS OF RELEASES TO SOIL AND AIR MEDIA

	LEVEL II	LEVEL III
ANALYTICAL TOOLS	Estimation equations using analytical sampling data (and/or monitoring data, if available).	Computer modeling; facility monitoring data
MEDIUM: Soil (e.g. from a lagoon or pond, spill, intentional placement in ground)	-surface soil: use sampling data ● average contamination: average sample concentration ● maximum contamination: highest sample concentration -subsurface soil: use sampling data, if available, or refer to: Schultz et. al., 1984	-surface soil: use monitoring data ● average contamination: take average sample concentration ● maximum contamination: take highest sample concentration -subsurface soils: use monitoring data, if available, or use computer modeling* to derive average and maximum concentration values of subsurface soils
MEDIUM: Air (e.g. via entrainment of dusts)	-refer to: ICF, Inc., 1985 and EPA, 1984c, for hazardous constituent release quantification methodologies - refer to soil conservation service sources for site-specific soil and climatic data for use in above, if necessary	-utilize air monitoring data (both upwind and downwind of the source) and/or use computer modeling to derive average and maximum contamination concentrations

---

* Models applicable to quantitative analysis of hazardous constituent release to soil and air media are referenced in Table B-6.

be wholly representative of conditions at the facility, and application of the analysis outcome should be limited to the following situations (EPA, 1984c):

- estimation of the level of release of specific hazardous constituents at a facility, and

- projection of approximate release reduction as a result of corrective measures taken at the facility.

In other words, the limited applicability of the level II release analysis to these situations should govern the permit writer's use of level II analysis in general. If the permit writer desires an estimate of environmental release which is highly accurate or wishes to use the analysis outcome to estimate the efficacy of corrective measures to a specified environmental release level, then level II analysis will not be sufficient; level III analysis will be required to obtain a more sophisticated and accurate estimate of release. However, if level III analyses are desired but are not able to be performed (e.g., due to lack of resources, analytical data, etc.), then professional judgement must be used in the level II analysis, in order to account for the inherent reductions in release rates over time and to specify more accurate estimates of environmental releases.

Assumptions/Limitations of Level III Hazardous Consitutent Release Analysis--

Level III hazardous constituent release analysis generally involves the use of modelling to specify exact estimates of environmental concentrations. Several criteria must be taken into consideration when selecting a level III model to quantify releases of hazardous constituents to soil. They include:

- data requirements of the model versus availability and reliability of resources; e.g., source sampling data or monitoring data, time, and finances,

- fit of the model to site-specific and hazardous constituent-specific parameters,

- form and content of model output: does it estimate mass loading to soils or air (i.e., environmental loading per unit time).

Models capable of quantifying release of hazardous constituents to surface soils (and the subsequent degree of contamination to subsurface soils) and air are referenced in Table B-6. Of note, is the necessity to match available source sampling data to the results of the model in order to validate the model's results. The consistency of the two estimates will also provide a measure of reliability for both sources of information.

Environmental Fate Analysis

Environmental Fate Analysis is the second step in quantitative exposure analysis. The purpose of quantitative environmental fate analysis is to generate estimates of the direction of migration and areal extent of contamination as well as the ambient concentrations of hazardous constituents within the soil media. The average release rate estimates derived from the release analysis (Step 1) serve as input to this analysis, and by application of environmental transport, transformation, and removal mechanisms, environmental fate estimates are calculated. Regardless of the level of exposure performed (e.g., level II or III), estimates of environmental concentrations which should be determined include: (1) maximum expected ambient concentrations (e.g., representing short-term worst-case conditions), and (2) average ambient concentrations (e.g., representing most-probable conditions over a long time period).

The suggested approach for evaluation of the environmental fate of hazardous constituents released to soils is to consider separately the major transport and transformation processes of the constituent released to each environmental medium of concern. In the case of releases to soil, both soil (as a direct release medium), and air (as an indirect medium, via entrainment of dusts) must be considered. Methods available for use in quantitative (level II and III) analyses of environmental fate of releases to soils (and indirectly, to air) are referenced in Table B-7. Limitations and assumptions inherent in analyses of environmental fate at these levels (II and III) are described briefly below.

TABLE B-6. COMPUTER MODELS APPLICABLE TO QUANTITATIVE ANALYSIS OF RELEASE AND ENVIRONMENTAL FATE IN SOIL AND AIR MEDIA*

MEDIUM: SOIL

For available models applicable to release environmental fate analysis in soils, the reader is referred to the following sources:

- Schultz et. al., 1984
- McNells et. al., 1984
- EPA, 1982a.

MEDIUM: AIR

For available models applicable to release and environmental fate analysis, the reader is referred to the following sources:

- EPA, 1982a
- GCA, 1983a
  GCA, 1983b.
- Schultz et. al., 1984
- McNells et. al., 1984
- ICF, Inc., 1985

---

*Descriptions and uses of available models are presented in these sources.

TABLE B-7. EQUATIONS AND MODELS AVAILABLE FOR LEVEL II AND LEVEL III ANALYSIS OF ENVIRONMENTAL (MIGRATION AND) FATE IN SOIL AND AIR MEDIA

	LEVEL II	LEVEL III
ANALYTICAL TOOLS	Estimation equations using analytical sampling data (and/or monitoring data, if available).	Computer Modeling; monitoring data
MEDIUM: Soil (e.g. from a lagoon or pond, spill, intentional placement in ground)	-surface soil: use sampling data • average contamination: take average sample concentration • maximum contamination: take highest sample concentration -subsurface soil: use sampling data, if available, or refer to: Schultz et. al., 1984	-surface soil: use monitoring data • average contamination: take average sample concentration • maximum contamination: take highest sample concentration -subsurface soil: use monitoring data, if available, or use computer modeling* to derive average and maximum concentration values of subsurface soils
MEDIUM: Air (e.g. via entrainment of dusts)	-refer to: Schultz et. al., 1984; ICF, Inc, 1985 for hazardous constituent environemtal fate quantification methodologies - refer to: soil conservation service sources for site-specific soil and climatic data for use in above, if necessary	-utilize air monitoring data (both upwind and downwind of facility, and/or use computer modeling* to derive average and maximum contamination concentrations

*Models applicable to quantitative analysis of environmental (migration and) fate in soil and air media are referenced in Table B-6.

Limitations/Assumptions of Level II Environmental Fate Analysis--

Level II procedures for quantifying hazardous constituent fate in soil and air media are based on the predominant mechanisms of transport within these media and generally disregard transfer or transformation processes. They produce conservative estimates of final ambient concentrations and environmental migration. The purpose of conservatism at this step in the exposure/risk estimation process is twofold: (1) to eliminate from additional consideration those potential exposure points which are not expected to be affected by hazardous constituents migrating from the source, and (2) to provide conservative estimates of hazardous constituent concentrations as input to subsequent exposure (e.g. intake or dose) and risk assessment. By disregarding the effects of transfer or transformation processes in the environmental fate analysis step, environmental concentrations utilized as input to exposure (and risk) analysis will tend to overstate actual ambient concentrations. At best, these concentrations will represent "worst-case" environmental constituent levels. The significance of each exposure pathway evaluated in the exposure analysis will therefore be conservatively estimated. This will aid in identification of those pathways which are of minimal, moderate, and major significance under presumed "worst-case" conditions.

Limitations/Assumptions of Level III Environmental Fate Analysis--

Level III environmental fate analyses generally involves use of computer models to specify exact estimates of environmental concentrations. When selecting a level III model to estimate environmental concentrations of released hazardous constituents (e.g., to soil or air), the permit writer should consider the following criteria (Schultz, et al., 1984):

- data requirements of the model versus availability and reliability of available resources: (e.g., source sampling or monitoring information, time, finances, and level of need),
- capability of the model to account for important transport, transformation, transfer processes.
- "fit" of the model to site-specific and hazardous constituent-specific parameters, and
- form and content of model output (e.g., does it address important questions regarding human exposure, environmental effects?).

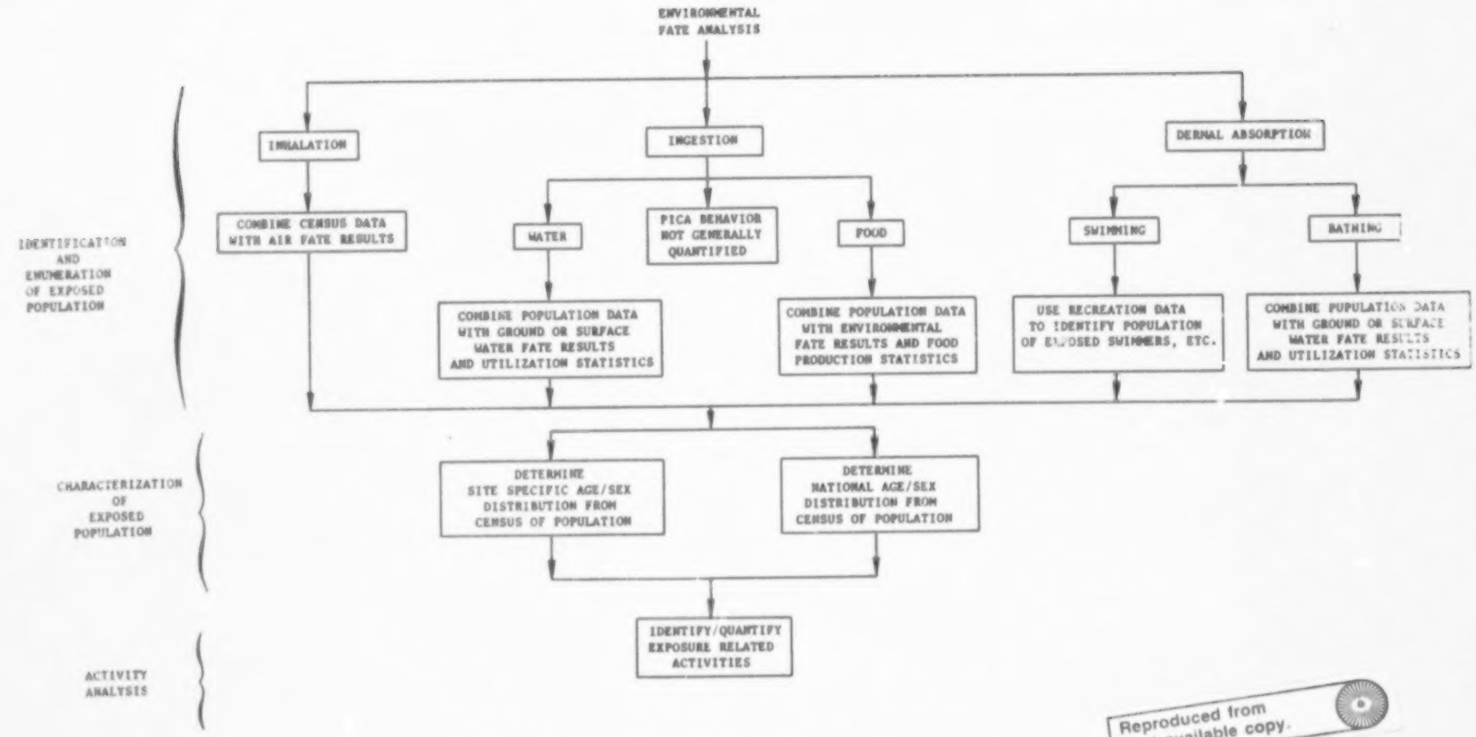
Again, it is important to note the necessity of comparing available source sampling and/or monitoring data to model output in order to "check" the reliability of both sources of information. Table B-6 references the models available for estimating environmental concentrations of hazardous constituents which have been released to and are expected to remain in the soil medium, and those which have been released to soils and entered the air medium, respectively.

Exposed Population Analysis

The final step of the quantitative exposure analysis process is the exposed population analysis. Input necessary for the exposed population analysis is derived from previous steps, hazardous constituent release analysis (Step 1) and environmental fate analysis (Step 2). For example, level II analysis of air contamination will yield isopleths (lines of equal concentrations of) hazardous constituents. Areas of soil contamination will also be identified and the levels of contamination quantified. These quantitative environmental levels are then considered together with information concerning potentially exposed populations (as described below) to identify and predict the likelihood of human (and non-human) contact with hazardous constituents released to soil. The analysis invovles determination of three parameters, as shown in Figure B-6. Briefly, they include:

(1) identification and enumeration of exposed populations; e.g., by considering the areal extent of contamination (as determined in step 2, environmental fate analysis), populations which potentially or actually come into contact with contaminated soil or air are identified. Populations consuming contaminated food products (e.g., vegetables grown in contaminated soils) are similiarly identified.

(2) population characterization; e.g., determining those groups within the exposed populations which, are expected to experience the greater risk than the average population (e.g., a sensitive sub-population) at a given exposure level, due to specific health effects of some hazardous constituents. Examples of such sensitive subpopulations include pregnant women, children, the elderly, and the chronically ill.


ENVIRONMENTAL FATE ANALYSIS
IDENTIFICATION AND ENUMERATION OF EXPOSED POPULATION
INHALATION
INGESTION
DERMAL ABSORPTION
COMBINE CENSUS DATA WITH AIR FATE RESULTS
WATER
PICA BEHAVIOR NOT GENERALLY QUANTIFIED
FOOD
SWIMMING
BATHING
COMBINE POPULATION DATA WITH GROUND OR SURFACE WATER FATE RESULTS AND UTILIZATION STATISTICS
COMBINE POPULATION DATA WITH ENVIRONMENTAL FATE RESULTS AND FOOD PRODUCTION STATISTICS
USE RECREATION DATA TO IDENTIFY POPULATION OF EXPOSED SWIMMERS, ETC.
COMBINE POPULATION DATA WITH GROUND OR SURFACE WATER FATE RESULTS AND UTILIZATION STATISTICS
CHARACTERIZATION OF EXPOSED POPULATION
DETERMINE SITE SPECIFIC AGE/SEX DISTRIBUTION FROM CENSUS OF POPULATION
DETERMINE NATIONAL AGE/SEX DISTRIBUTION FROM CENSUS OF POPULATION
ACTIVITY ANALYSIS
IDENTIFY/QUANTIFY EXPOSURE RELATED ACTIVITIES

Reproduced from best available copy.

Figure B-6. Quantitative exposed population analysis.

Source: Schultz, et. al., 1984.

(3) activity analysis; e.g., determining the mix of human activities conducted by the population through which exposure occurs. Key activity-related exposure determinants to be quantified for each exposure route relevant to hazardous constituent releases to soil (e.g., inhalation, ingestion, and dermal contact) are shown in Table B-8. The procedure for conducting the exposed population analysis is the same for a level II assessment as for a level III assessment, except for the fact that average or estimated levels of hazardous constituents are used in level II, and more accurate, source-specific data are used in level III. The three parameters necessary for exposed population analysis are discussed briefly below. The reader is referenced to other sources of information if such information is not presented here.

Identification and Enumeration of Exposed Populations--

Identification and enumeration of exposed populations is the first parameter necessary to perform the exposed population analysis step of the quantitative exposure analysis. The primary population database that can be accessed to determine the size, distribution, and demographic characteristics of a geographically-defined population is the Census of Population. For further information on the aquisition and use of census data, the reader is referred to EPA, 1984c. The manual also provides guidance for the identification and evaluation of human populations exposed to hazardous constituents in air (via inhalation), food (via ingestion), and soil (via inhalation/ingestion and direct contact).

Population Characterization--

Population characterization is the second parameter necessary to perform the quantitative exposed population analysis. Again, the reader is referred to EPA, 1984c, for guidance in defining this parameter of the exposed population analysis.

Activity Analysis--

Activity analysis is the third and final parameter necessary to perform quantitative exposed population analysis. The activity analysis is fairly straightforward; however, the permit writer is required to make some generalizations. In the analysis, the activities of the members of a given population or subpopulation are determined in order to predict the level of

TABLE B-8. KEY ACTIVITY-RELATED EXPOSUR DETERMINANTS TO BE QUANTIFIED IN THE EXPOSED POPULATION PHASE FOR EXPOSURE ROUTES RELEVANT TO RELEASES TO SOIL[a]

INHALATION:

- Length of time (frequency and duration) spent in each related activity.
- Nature of the activity in terms of light, medium, heavy, or maximum exertion (per unit time).

INGESTION:

- Amount of contaminated food or water ingested (per unit time).

DERMAL EXPOSURE:

- Length of time (frequency and duration) spent in each related activity per unit time.
- Location of exposure (e.g. on human body) and areal extent of exposure.

---

[a] Many of these exposure criteria are considered as "standards" in the following sources: Schultz et. al., 1984; ICF, Inc., 1985. The reader is referred to these information sources in his analysis of human activity related to exposure to hazardous constituents.

Source: Schultz et. al., 1984.

exposure which is actually experienced. Generalization is involved in predicting the human activity patterns which result in exposure to environmental contamination. For example, persons whose lifestyle or employment involves frequent strenuous activity will ventilate larger volumes of air per unit time than will those persons living a more leisurely lifestyle, and will therefore experience a greater degree of exposure to airborne constituents. Activity patterns which affect other exposure routes are similarly analyzed. Because human behavior is difficult to predict, hypothetical situations (i.e., scenarios) are developed to represent the exposure associated with human activity patterns. Human activity scenarios typically involve determination of "average" and maximum (i.e., "worst-case") population exposures, by determining the extent (i.e., duration, frequency) to which the population comes into contact with average and maximum environmental concentrations. The quantitative exposed population analysis is performed by first defining the three parameters (cited above): (1) exposed population identification and enumeration, (2) exposed population characterization, and (3) exposed population activity analysis. The results of the exposed population analysis are then combined with those of the first and second steps of the quantitative exposure analysis process (i.e., hazardous constituent release and environmental fate analysis), and human exposure is quantified. There are basically two measures of quantitative human exposure; they are:

(1) intake estimates, and

(2) dose estimates.

The use of a particular measure is dependent upon assumptions and limitations inherent in the development of the measure. Both of these measures (estimates) of human exposure are discussed briefly below; use of these estimates in the risk characterization process and their inherent limitations and assumptions are discussed in more detail in Section 6, risk characterization.

Intake Estimates--

One quantitative estimate of human exposure is intake (i.e., the amount of substance taken into the body per unit body weight per unit time). The intake estimate does not take into account bodily absorbtion of the hazardous constituent, and is therefore a more conservative estimate of human exposure than is the dose estimate. Given the limited amount of available human absorbtion data, its use is more applicable to a variety of exposure situations and hazardous constituents than is the dose estimate. In other words, the permit writer is not limited (in his quantitative exposure analysis) to the amount of available data concerning absorbtion rates for specific chemicals through specific biological barriers. By using information acquired from the quantitative environmental fate and exposed population analyses (steps 2 and 3 in the overall quantitative exposure analysis) together with standard "intake" values (e.g., average ventilation rates, average body weights) he is able to estimate human intake resulting from exposure. An example of intake estimation for exposure to airborne constituents is shown below. The standard intake valves utilized in this equation (e.g., the average ventilation rate and body weight) were derived from ICF, Inc., 1985).

average (or maximum) environmental contaminant concentration (in airborne dusts)	*	average daily ventilation rate of exposed individual	÷	average body weight of exposed individual	=	average (or maximum) daily intake

$$\left[\ 3\ \text{mg/m}^3 \quad * \quad \underset{\text{adult}}{20\text{m}^3\text{/day}} \quad \div \quad \underset{\text{weight (adult)}}{70\text{ kg body}} \quad = \quad \underset{\text{intake}}{0.857\text{ mg/kg/day}}\ \right]$$

Intake values are calculated separately for exposures to hazardous constituents in each medium identified in a complete exposure pathway i.e., each medium identified in the release/transport/exposure pathway). For releases to soil, relevant exposure media are soil and air (and indirectly, biota). Standard assumptions of human intake (e.g., average ventilation rates and average body weights) are utilized to derive the actual intake estimates from exposure to these media. For further information and guidance on the use of intake assumptions and equations to estimate human intake values from exposure to air contaminants, the reader is referred to Schultz, et al., 1984. For guidance in the assessment of less common, but potentially significant routes of exposure (e.g., direct contact with contaminated soils, ingestion of inhalated contaminated dusts or food products). The EPA Office of Emergency and Remedial Response (OERR) Washington, D.C., is developing further information in this area.

Dose Estimation--

A second estimate of quantitative human exposure is the dose estimate; i.e., the amount of substance which is actually absorbed by the body as a result of exposure to contaminated media. It is derived by considering existing concentrations of hazardsou constituents in environmental media together with the frequency of exposure, route of exposure, and amount of contaminant contacted per exposure (i.e., the "exposure coefficient"). Like the intake estimate, the dose estimate also assumes standard population intake rates for various routes of exposure (e.g., ventilation rates, consumption rates). In addition, it also assumes standard rates of absorption for chemicals into the human body. The dose estimate is, therefore, less conservative than is the intake estimate; but, provided that the assumed absorption rate used in the dose calculation is accurate for the hazardous constituent and site of biological uptake of concern, it provides a more specific and accurate measure of human exposure. Alternatively, if the assumed absorption rate used in the dose calculation is not accurate for the hazardous constituent and site of biological uptake of concern, then the dose estimate will not provide an accurate measure of human exposure, but will tend to understate it. Further information and guidance on estimating human dose resulting from exposure to releases to soil via relevant exposure routes (e.g., direct contact, inhalation, and ingestion), the reader is referred to Schultz, et al., 1984. An example of dose estimation via direct contact with hazardous constituents in soils is shown in Figure B-7, (Schultz, et al., 1984). Assumptions inherent in the calculation of human dose estimates are discussed under risk characterization.

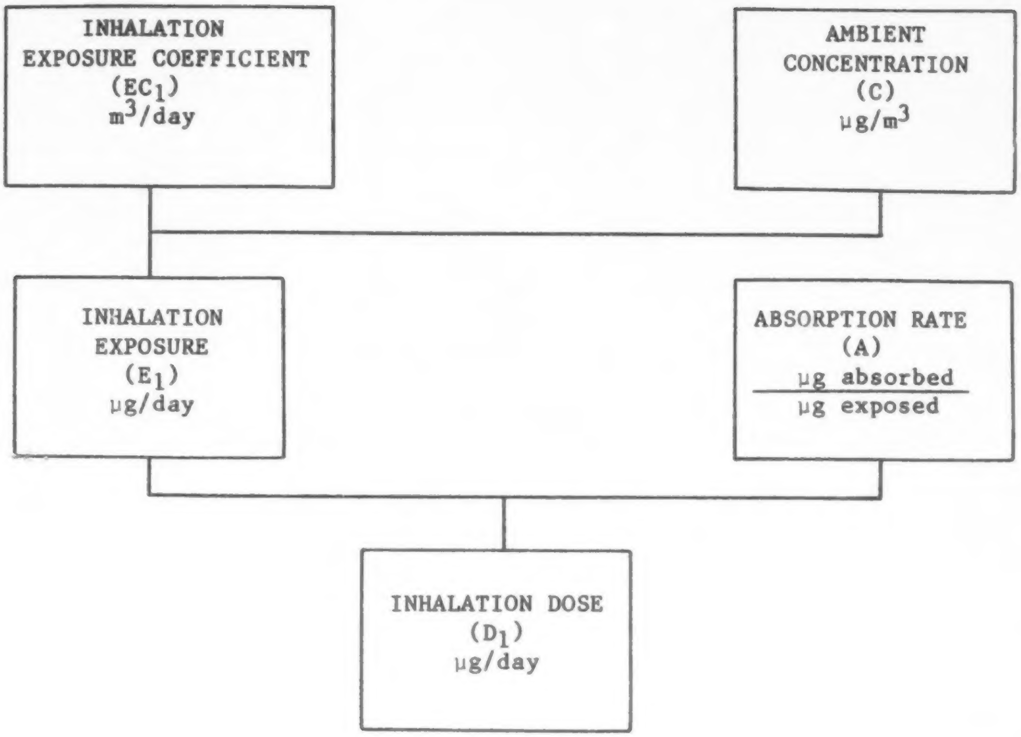


Figure B-7. Inhalation dose calculation.

Source: Schultz, et al., 1984.

Summary--

In summary, quantitative exposure analysis involves 3 steps, each of which is quantitatively analyzed. These steps include:

(1) hazardous constituent release analysis,

(2) environmental fate analysis, and

(3) exposed population analysis.

The output of each of these steps serves as input to the subsequent step; the final outcome of the analysis process is a quantitative measure of human exposure, expressed as either intake or dose. The permit writer must decide which estimate of human exposure will be calculated, however, consideration of the following criteria can aide in the decision process:

(1) Toxicological Profiles: What are the hazardous constituents of concern, and by what routes of exposure do they exert their primary toxicological effects? Is adequate data available to define biological absorbtion rates for the target organs of concern? For instance, if a hazardous constituent has been widely researched, accurate human absorbtion rates (for biological target organs of concern) may be available, and dose estimation will be possible.

(2) Level of Need: Are estimates of human dose (resulting from exposure) desired, given the projected level of significance of human exposure (estimated in the level I analysis) and the intended use of the exposure estimate in establishing permit conditions or corrective measures?

For instance, if exposure to a hazardous constituent has been determined in level I analysis to be only minimally or moderately significant, efforts to define exact human dose may not be necessary; intake estimates will not only provide more conservative estimates of human exposure for the specified exposure pathways, but are also easier to calculate and are generally based on fewer assumptions than are dose estimates. However, if an accurately defined measure of human exposure is required in order to establish permit conditions or evaluate the efficacy of corrective measures, (given the availability of human absorbtion data), dose calculations preferred over intake estimates.

Both human intake and dose estimates are equally useful measures of human intake; and both can be used to form the basis of quantitative risk characterization. Descriptions, uses, informational requirements, and limitations of both qualitative and quantitative risk assessment strategies will be discussed in the following section.

RISK CHARACTERIZATION

Components of the Risk Characterization Process

The process of determining the risk to human (and non-human) populations associated with exposure to contaminant releases to soils involves input from two components:

- Exposure Assessment to determine the magnitude, pathways, and routes of human (and non-human) exposure to hazardous constituents; and
- Hazard Assessment, to determine the chemical toxicity and related hazard of a contaminant to which there is exposure.

By combining the results of these two components (i.e., exposure and hazard assessment), the actual and potential health risks resulting from exposure to hazardous constituent releases to soils can be characterized. Like the exposure assessment process, the risk characterization process can be either qualitative or quantitative. Determination of the risks to human (and non-human) populations (as a result of exposure to environmental constituents) serves two purposes for the permit writer:

(1) It provides a way to determine the level and means of correction measures necessary to eliminate the risks to populations associated with release to environmental media, and in the absense of existing standards and guidelines,

(2) It provides an approach for evaluating public health impacts associated with hazardous constituent exposures in order to establish permit conditions.

The following two sections provide brief descriptions of these two components of the risk characterization process, exposure assessment and hazard assessment, and provide guidance for the use of these components to qualitatively and quantitatively evaluate risk.

Hazard Assessment--

Following exposure assessment, a hazard assessment is the next component of the risk characterization process. The hazard assessment is essentially a two-step process involving both "hazard identification" and "dose-response" assessment for the releases of concern. The purpose of the hazard identification is to determine the nature and extent of health and environmental hazards associated with exposure to hazardous constituents at the facility.

The first step in the hazard assessment, the hazard identification, is a qualitative evaluation of the scientific data to determine the nature and severity of actual or potential health and environmental hazards associated with exposure to a hazardous constituent. The hazard identification involves a critical evaluation and interpretation of toxicity data from epidemiological, clinical, animal and _in vitro_ studies and results in a toxicity profile for each hazardous constituent of concern. Toxicity profiles present a review of the primary literature on the types of adverse effects manifested (e.g., chronic, acute, carcinogenic, etc.), doses employed, routes of administration (e.g., oral, dermal, inhalation, etc.), the quality and extent of test data, the reliability of the test data and other factors. Toxicity profiles provide the weight-of-evidence that the hazardous constituents of concern pose potential hazards to human health or the environment.

Once the hazard identification determines that a hazardous constituent is likely to cause a particular adverse effect, the next step is to determine the potency of the chemical. The second step in the hazard assessment, the dose-response assessment, is a quantitative estimation of risk from exposure to a toxic chemical. It defines the relationship between the dose of a chemical and the incidence of the adverse effect. (Life Systems, Inc., 1985).

The dose-response assessment involves presentation of all pertinent criteria, guidelines, and standards for the protection of human health and the environment. The dose-response assessment is performed for chemicals which are carcinogens as well as non-carcinogens. A brief discussion of the components of the dose-response assessment for both of these types of chemicals is as follows.

For dose-response assessment of toxic substances (non-carcinogens) EPA has established no observed adverse effect levels (NOAELs); no observed effect levels (NOELS) and lowest observed adverse effect levels (LOAELs) based on relevant toxocologic data. Using these values and incorporating a safety factor (e.g., 10, 100, 1000, etc) the acceptable daily intake (ADI) can be calculated. The ADI is defined as the largest amount of toxicant (in mg/day) to which a 70-kg person can be chronically exposed which is not anticipated to result in any adverse effects. Of importance to note is that ADIs are calculated for individual compounds and do not reflect the possible adverse effects resulting from exposure to other chemicals present or the synergistic and/or antagonistic effects that a chemical mixture may produce. Use of ADI values to assess hazard associated with chemical mixtures will be discussed in a subsequent section.

For dose-response assessment of carcinogenic chemicals the EPA Carcinogen Assessment group (CAG) has developed "unit risk" levels, or chemical potency indexes. These unit risk levels are expressed as the lifetime human cancer risk per mg/kg body weight/day. They are based on the best available human and animal study data and are derived using mathematical models of the chemical's dose-response relationship. They are not, however, adjusted for facility-specific conditions.

EPA has developed toxicity hazard profiles on a number of hazardous constituents. These profiles define the "acceptable levels" of exposure to non-carcinogenic chemicals and the estimates of unit cancer risk for carcinogenic chemicals. Toxicological hazard profiles of these substances can be found in a set of Health Effects Assessments (HEAS) for hazardous chemicals typically found at uncontrolled waste sites or which may be disposed of at RCRA facilities. Copies of the HEAS for specific chemicals are available from EPA's Office of Emergency and Remedial Responses (OERR) in Washington, D.C. In addition to the HEAS, toxicological information for hazardous constituents of concern can be found in the Toxicological Profiles available through EPA's Office of Waste Programs Enforcement in Washington, D.C.

The end-product of a hazard assessment is a qualitative description of the toxic properties of the hazardous constituents of concern at the site and a quantitative index of the toxicity for each constituent at the site, if the data are sufficient for such an assessment. (Life Systems, Inc., 1985). Use of the hazard assessment information (for both carcinogens and non-carcinogens) together with the exposure analysis information, as generated in the previous step, to characterize risk to human (and non-human) populations resulting from exposure to releases to soils will be discussed in the following section levels of risk characterization (e.g., qualitative, quantitative) and the criteria used to select the appropriate level of risk characterization to perform will also be presented.

LEVELS OF RISK CHARACTERIZATION

The risk characterization process can be either qualitative or quantitative in nature. The decision as to which level of risk analysis is to be performed is dependent primarily on two factors: (1) the primary effect of hazardous constituents involved (e.g., carcinogenesis or toxic effects), and (2) the level of exposure analysis (e.g., qualitative or quantitative) performed prior to the risk characterization.

For chemicals which are carcinogens or suspected carcinogens quantitative risk characterization is usually performed. For non-carcinogens, either qualitative or quantitative risk characterizations can be performed; the decision as to which type is to be performed is usually dependent on the level of exposure analysis conducted prior to the risk characterization. If the exposure analysis performed prior to the risk characterization is qualitative in nature, qualitative risk characterization must be performed; e.g., no human exposure estimates (such as intake or dose levels) have been calculated, therefore quantitative risk characterization is not possible. If the previous exposure analysis was quantitative in nature, the permit writer has a choice as to whether to use those estimated human intake or dose levels to perform a quantitative risk analysis or to simply perform a qualitative analysis. To make this decision, the following additional criteria should be considered: (1) the level of expertise should be needed (and available) to perform the risk analysis; e.g., quantitative risk characterization generally requires a greater amount of expertise in the field of toxicology and public health than does qualitative risk analysis due primarily to the greater number of assumptions and generalizations needed to be made (to be discussed below); and (2) the time available to perform the risk characterization; e.g., quantitative risk characterization is generally more complex and time-consuming than is qualitative risk characterization.

The following sections describe the two levels of risk characterization (e.g., qualitative and quantitative); guidance in the performance of these risk characterization processes is also included. For additional information regarding risk characterization processes, the reader is referred to sources given below.

Qualitative Risk Characterization

A qualitative risk characterization is usually performed subsequent to a qualitative exposure analysis and provides a relative index of human risk associated with exposure to hazardous constituent releases to soil, and indirectly to other contaminated media, such as air (through inhalation) or biota (through ingestion). Qualitative risk characterizations are usually performed for chemicals which are non-carcinogens, but can also be performed for chemicals which are carcinogens and which have either: (1) been qualitatively evaluated in the (previous) exposure analysis or, (2) have been quantitatively evaluated in the previous exposure analysis and are expected to pose little or no risk to human (or non-human) health.

The qualitative risk characterization process involves an assessment of two components: (1) the toxicological and biomedical evidence available for the hazardous constituents of concern (as discussed previously in the hazard assessment), and (2) the exposure potential for constituents of concern (as determined previously in the exposure assessment).

The first step in the qualitative risk characterization involves an evaluation of all pathways of human (and non-human) exposure determined to be "complete" in the exposure analysis. The relative magnitude (significance) of exposure (rated as high, moderate, or low) for each exposure pathway is also considered, and provide a means of preliminarily determining which routes of exposure potentially pose the greatest risk to human (and non-human) health.

The next step in the qualitative risk characterization process involves an evaluation of the toxicological and biomedical evidence of hazardous constituents of concern, (as determined in the previous hazard assessment phase) to determine the nature and severity of actual or potential health (and environmental) hazards associated with these hazardous constituents of concern.

By combining the information on the relative likelihood and significance of exposure to human (and non-human) population via the pathways and routes (identified in the exposure analysis) with the probability and nature of potential hazards of the chemicals involved (identified in the hazard assessment), the relative probability, magnitude, and type of risks to human (and non-human) populations can be determined. Determination of risk to these identified populations (receptors) is qualitative in nature. However, for many conditions involving actual or potential exposure to human (and non-human) populations, a qualitative characterization is adequate for describing the risk to these receptors. Whether or not a qualitative risk characterization is adequate is dependent primarily on: (1) the level of need of the permit writer (e.g., the permit writer does not need to use the risk characterization to evaluate the efficacy of corrective actions or to establish permit conditions to a defined level), and (2) the projected significance of the risk to specific receptors, as determined in the exposure analysis. For instance, if the chemicals of concern are of limited toxicity, are at low environmental levels or are not expected to be associated with exposure to human (or non-human) receptors, a qualitative characterization may be adequate to describe the risk to these receptors.

QUANTITATIVE RISK CHARACTERIZATION

A quantitative risk characterization is usually performed for chemicals which are known or expected carcinogens, and is frequently performed for chemicals which are non-carcinogens. Despite the type of hazardous constituents involved, a quantitative risk characterization can only be performed subsequent to a quantitative exposure analysis. In other words, if the permit writer, upon initial consideration of a cause of action to take a given hazardous constituent release to soils, feels that he is not in need of an indepth evaluation of exposure (and risk) or that available analytical data is not complete or accurate enough to be used to perform an indepth exposure (or risk) analysis, then he does not need to perform a quantitative risk characterization. He should, instead, perform qualitative (risk and exposure) analyses.

A quantitative risk characterization consists of comparing the projected human exposure levels (e.g. the intake or dose levels, as determined in the previous section, quantitative exposure analysis) of the hazardous constituents present to the acceptable dose levels (e.g., standards, criteria and guidelines) established by various goverment agencies for these compounds. Such comparisons give an indication of the magnitude of the adverse health and environmental effects that may result from exposure to these substances. The type and extent of risk posed by any facility depends upon the nature, duration, and level of exposure, as well as the type of populations exposed. For most hazardous constituent sources, the human (and non-human) populations and conditions of exposure potentially affected by the facility are quite diverse and cannot be assimilated by a single condition of exposure to give a single absolute risk for the source. For this reason, most sources are evaluated in terms of the risk posed to populations via separate pathways and routes of exposure. To predict the risk ot populations associated with exposure to environmental constituents, hypothetical exposure scenarios are developed. Exposure scenarios describes distinct exposure conditions (e.g. estimated frequency duration exposure) to average and maximum ambient environmental constituent levels.

Methods of quantitatively characterizing the risks to human (and non-human) populations associated with exposure to environmental media contaminated as a result of release to soils is presented below. Quantitative risk characterization processes for evaluating chemicals which are non-carcinogens as well as carcinogens is presented. In classifying a chemical as a carcinogen (versus a non-carcinogen) it is meant that the primary effect (endpoint) of the chemical is carcinogenesis, although the chemical may have other non-carcinogenic (e.g. toxic) endpoints. Because it is common for a source of hazardous constituent release to involve more than one type of chemical, characterization of risks associated to chemical mixtures is also presented.

Quantitative Risk Characterization of Non-Carcinogens

A quantitative risk characterization for non-carcinogens involves consideration of: (1) the existing standards guidelines, and criteria developed by various regulatory agencies which represent the best scientific estimates of health risk at given environmental concentrations (as presented in the hazard assessment phase) and, (2) the (human) intake estimates calculated in the exposure analysis phase, for each exposure route of concern.

The human health guidelines established for non-carcinogens are represented by the NOAELs, NOELs, LOAELs, and incorporating a safety factor to account for uncertainty in the data on which these indices are based, ADI values. The ADI is commonly defined as the largest amount of toxicant in mg/day for a 70 kg person which is not anticipated to result in any adverse effects after chronic exposure. To perform the risk characterization, the first step is to consider the exposure scenarios for each route and condition of exposure at the facility (as developed in the quantitative exposure analysis).

For each exposure scenario (e.g., representing average, most-realistic conditions, or maximum, worst-case conditions of exposure) the level of risk is characterized. To characterize the risk associated with exposure conditions represented in each scenario, the estimated (human) intake level (for the route of exposure being evaluated in the scenario) is compared with the ADI value for the hazardous constituent of concern. If the estimated intake level is in excess of the ADI value, then the exposure conditions described by the scenario represent an "unacceptable" risk to human health. If the opposite is true, e.g. the intake value for that route of exposure and chemical is less than the corresponding ADI value, then the conditions represent an "acceptable" risk to human health. The intake values for each route of exposure of concern are evaluated in a similar fashion. For releases to soils, this the relevant routes of exposure include:

- Direct contact (with soils).
- Inhalation (of fugitive dusts), with possible reingestion".
- Ingestion of food products and soil).

There are limitations and assumptions inherent in any risk characterization process especially when the characterization process involves routes of exposure which are difficult to assess. Some of the limitations and assumptions inherent in characterizing risks via these routes of exposure are present in the final section.

Quantitative Risk Characterization of Carcinogens

Like the quantitative risk characterization process for non-carcinogens, the process of characterizing risks associated with exposure to chemicals whose primary effect is carcinogenesis involves consideration of the existing standards, guidelines and criteria which represent the best scientific estimates of health risk at given environmental concentrations as presented in the hazard assessment phase. Unlike non-carcinogens, however, the second consideration in evaluating risks associated with exposure to chemicals which are carcinogens is the estimated dose incurred by receptors, as calculated in the previous quantitative exposure analysis phase, for each route of exposure of concern.

For chemicals which are carcinogens, the guidelines used to perform quantitative risk characterizations are called "risk levels", i.e., the incremental risk of developing cancer from exposure to the hazardous constituent of concern. The EPA in its Ambient Water Quality Criteria Documents uses a range of risk levels from 10^{-5} to 10^{-7} to describe the increased risk of cancer predicted for exposure to low dose levels of chemicals (e.g., which are typical of environmental conditions). A one-in-one-million increase in risk (10^{-6}) is the mean value of this range and is often used as a baseline level. This base level does not necessarily represent a level of "acceptable" risk, but is used as reference for which assessments of risk to populations can be made.

The calculated environmental cancer risks are derived using the projected exposure (e.g., dose) levels calculated in the exposure analysis phase and the measure of chemical hazard or potency associated with that chemical (the unit risk level presented in the hazard assessment phase. The calculated cancer risk level is compared to the baseline value of 10^{-6}, in order to provide an indication of the magnitude of the risk present. These resulting risk estimates are interpreted as probabilities of incremental cancer risks over lifetime exposure.

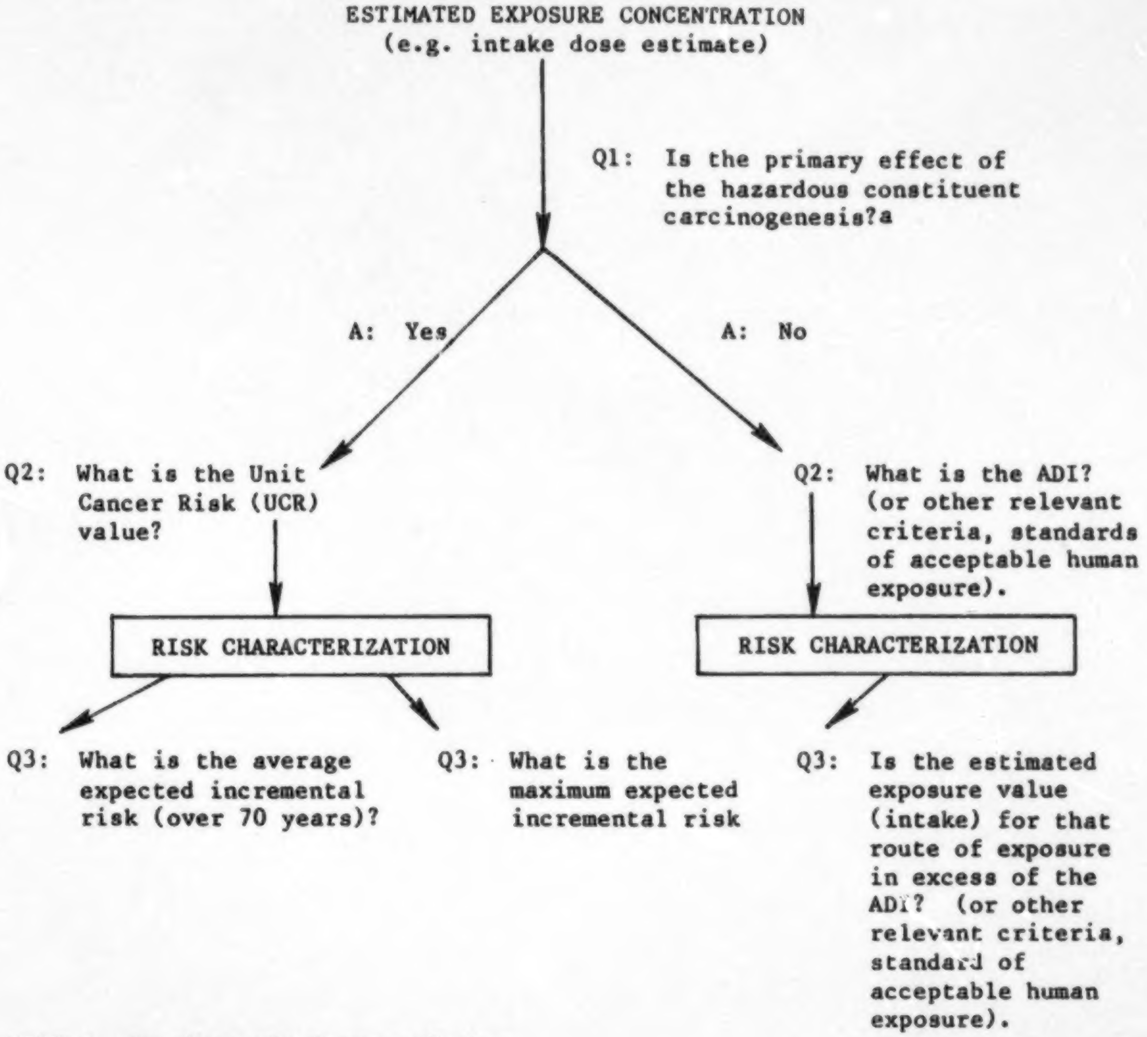
To perform the quantitive risk characterization for carcinogens the first step is to consider the exposure scenarios developed in the previous exposure analysis phase. For each exposure scenario, (e.g., those representing average, most-realistic conditions, as well as those representing maximum, worst-case conditions of exposure), the risk is characterized. To characterize the risk associated with the hypothetical exposure conditions represented in each scenario the estimated human dose value (calculated in the quantitative exposure analysis phase) is multiplied by the unit risk level for the chemical of concern. The resulting estimate of risk is then compared with the baseline risk value of 10^{-6} to predict the incremental increase in risk associated with the exposure route and scenario being evaluated. The flow diagram in Figure B-8 shows how the human dose value (calculated in the quantitative exposure analysis phase) can be used to predict risk associated with exposure to a given medium, in this example, soils. The process depicted in the diagram can be used to estimate the risks associated with all routes of exposure being evaluated, provided that estimates of dose for the exposure routes are provided.

An example of a typical risk calculation is presented below:

Risk = daily dose *(carcinogenic) unit risk factor
over 70 years
of life

Of importance to note is that this equation can only be used at low environmental levels for hazardous constituents of concern. For sources where chemical intakes may be large (e.g., carcinogenic risk labove 0.10), an alternate model should be considered. In this situation, the permit writer should consult EPA Headquarters for guidance in use of the appropriate model.

It should be recognized that, like the calculated non-carcinogenic risk estimate, the carcinogenic risk estimate is dependent on numerous assumptions, and many uncertainties and limitations are inherent in the process. The following section briefly describes some of the uncertainties and assumptions


ESTIMATED EXPOSURE CONCENTRATION
(e.g. intake dose estimate)
Q1: Is the primary effect of the hazardous constituent carcinogenesis?[a]
A: Yes
A: No
Q2: What is the Unit Cancer Risk (UCR) value?
Q2: What is the ADI? (or other relevant criteria, standards of acceptable human exposure).
RISK CHARACTERIZATION
RISK CHARACTERIZATION
Q3: What is the average expected incremental risk (over 70 years)?
Q3: What is the maximum expected incremental risk
Q3: Is the estimated exposure value (intake) for that route of exposure in excess of the ADI? (or other relevant criteria, standard of acceptable human exposure).

RISK = Carcinogenic Potency Factor *Average (or Maximum) expected lifetime dose

- present assumptions and uncertainties of results

- present assumptions and uncertainties of results common in characterizing risks associated with exposure to releases to soils for exposure routes of concern (e.g., direct contact, inhalation, and ingestion). For additional information on characterizing risks to human populations via these routes, the reader is referred to ICF,Inc., 1985.

---

[a] This assumes that the primary effect of the hazardous constituent is carcinogenesis; other noncarcinogenic endpoints can be evaluated via the method of risk evaluation depicted here.

Figure B-8. Schematic flow diagram of alternate methods of quantitative human risk characterization (given a determined dose incurred by receptor populations).

ASSUMPTIONS AND UNCERTAINTIES IN THE RISK CHARACTERIZATION PROCESS

Some of the major sources of uncertainty in any risk characterization process involve the hazard information for the chemicals of concern. Some common sources of uncertainty include: (1) the toxicity information used to estimate risks to human populations which is derived from animal studies, and must be extrapolated to humans; and (2) many of the toxicity studies are performed at high dose levels and must be applied to situations of low level environmental contaminant levels, typical of chemical releases; extrapolation from high to low doses increases the uncertainty in the results. Uncertainty can also be introduced at the exposure analysis phase, such as when exposure modeling (e.g., level II or III analysis using equations or models, respectively) is used in the calculation of intake or dose and which is based on many simplifying assumptions. Uncertainty is almost always introduced when the possible routes of exposure are difficult to qualify and quantify, although they may be extremely important to certain populations at risk. The following subsections describe some of the assumptions and uncertainties inherent in the characterization of risk associated with exposure via pathways and routes relevant to hazardous constituent releases to soils; e.g., direct contacts (with contaminated soils), inhalation of airborne particulates to which hazardous constituents have adsorbed with possible reingestion, and ingestion of food products (into which hazardous constituents in soil have been uptaken).

Dermal Contact with Contaminated Soils

Dermal contact (with contaminated soils) is a route of exposure for which there is limited information on which to base estimates of human risk. Characterization of risk for this route of exposure therefore requires making numerous assumptions, and a cetain degree of uncertainty is inherent in the evaluation. Many of these uncertainties are introduced at the exposure analysis phase with the development human exposure scenarios and the estimation of the frequency and duration of exposure. Other uncertainties are introduced at the hazard assessment phase with the estimation of human absorbtion percentages for the hazardous constituents of concern. Some of the assumptions and uncertainties inherent in characterization of risk for this route of exposure are as follows:

- determination of the amount of soil actually contacting the skin (during exposure), and the relative amount of pure hazardous constituent to which there is exposure,
- determination of the parameters associated with the part of the body contacted (e.g., surface area, actual part of body contacted, etc.),
- the percent absorbtion of the hazardous constituent contacting the body (e.g. based on the physical/chemical properties of constituents involved, available human absorption data, etc.),
- age of individuals contacted,
- human activity pattern associated with exposure (e.g., frequency, duration exposure, etc.), and
- human activity pattern after exposure (e.g. washing, bathing, eating, etc.).

Any assumptions and uncertainties introduced into the risk characterization process should be identified and presented. Consideration of these limitations will help to more accurately interpret the risk estimates that are generated.

Ingestion of Contaminated Soils (by a Child Exhibiting Pica)

Ingestion of contaminated soils is not a common route of human exposure, and primarily involves young children who come into contact with contaminated soils (e.g. while playing) and either accidentally ingest the soil or exhibit pica, an abnormal craving for non-food objects. Because exposure via this route is expected to be infrequent, and generally at low levels, the human risks associated with the exposure are usually not considered significant. An exception would be under circumstances involving close proximity to the facility of an area heavily utilized by children (e.g. a playground) in which exposure via this route would be more common. The assumptions and limitations inherent in risk characterization for this route of exposure are introduced primarily at the exposure analysis phase (e.g. with the development of exposure scenarios and the determination of frequency and duration of exposure) and the hazard assessment phase (e.g. with the estimation of the amount of absorbtion of the chemical into the body after ingestion). They are as follows:

- determination of human use areas near the facility and the associated human activity patterns,
- determination of the frequency, duration, and quantity of soil exposure,
- determination of age of exposed population, and
- determination of the percent absorption of hazardous constituents into the body upon ingestion.

Again, the assumptions and limitations introduced into the risk characterization process for this route of exposure should be presented with the interpretation of the calculated risk estimates.

Inhalation (if Airborne Particulates to Which Hazardous Constituents Have Adsorbed) with Possible Reingestion

The estimation of human risk assessment associated with exposure via inhalation contaminated dusts (e.g. airborne particulates) has been widely researched, and information relevant to the estimation and interpretation of risk estimates calculated for this route of exposure are presented primarily in two sources: (1) ICF, Inc., 1985 (Draft EPA Superfund Health Assessment Manual), and (2) Schultz, et al., 1984 (Draft EPA Superfund Exposure Assessment Manual).

Despite the availability of information for use in characterizing risks associated with exposure via inhalation of airborne particulates, little evidence is available for use in characterizing risks to human populations exposed to hazardous constituents via reingestion of inhaled particulates. Exposure via this indirect route is generally considered of limited significance due to the speradic nature of the exposure and the generally low levels of hazardous constituents to which there is exposure. In brief, some of the assumptions and uncertainties inherent in the characterization of risk associated with exposure via this route include:

- determination of duration, frequency, and quantity of air hazardous constituent exposure;
- determination of the age of exposed population (e.g. as it affects the average ventilation rate);
- determination of the percent absorbtion of the chemical of concern within the respiratory system;
- determination of the particulate size (and its affect on absorbtion in the respiratory tract); and
- determination of the extent to which reingestion of respired particulates occurs, and the resulting absorbtion rate of the chemicals in the digestive tract.

Again, any assumptions and limitations introduced into the risk characterization process should be presented.

Ingestion of Biota (Into Which Hazardous Constituents Have Been Uptaken)

Ingestion of biota is a route of human exposure for which risk characterization is generally very difficult to perform. This is due primarily to the limited availability of data to define the potential for uptake of hazardous constituents by plant species. Because of this common limitation, many assumptions must be made during the risk characterization process in order to define the extent of contaminant uptake by biota and the subsequent risk to human populations via ingestion.

Some of these assumptions and uncertainties include:

- determination of levels of hazardous constituents in plants exposed to contaminated soils and subsequently ingested;
- determination of the frequency, duration, and quantity of hazardous constituent exposure;
- absorbtion rate of ingested hazardous constituents; and
- age of population exposed.

Because there is limited information with which to perform risk characterizations for this route of exposure, quantitative risk characterizations are generally not possible. Quantitative risk characterization would involve direct sampling and analysis of the food products, and oftentimes this information is not available. Characterization of risks associated with exposure via this route is, therefore, generally quanlitative in nature.

SUMMARY

In summary, the risk characterization process involves assessment of two components, the exposure assessment and the hazard assessment. By combining the information in each of these components, actual or potential risks to human health and the environment can be characterized. Risk characterizations can be either qualitative or quantitative. The decision as to which level is performed is dependent primarily on the level of exposure analysis performed prior to the risk characterization (e.g. qualitative, quantitative). Regardless of the level of risk characterization performed, however, the outcome of the analysis is a determination of the actual or potential risks to human (and non-human) populations resulting from exposure to media contaminated as a result of release to soils. Because there is no one set method for performing risk characterizations, the risk characterization process used to evaluate each pathway and route of exposure for a given environmental medium involves making numerous assumptions. This is particulary true for exposure pathways and routes which are difficult to characterize. The making of assumptions introduces a certain amount of uncertainty into the risk characterization process. Because of this, the results of the risk characterization process must be cautiously interpreted. Despite the inherent uncertainty in the results of the risk characterization process, however, the information so derived can be used, at a minimal, to identify potential risks to human (and non-human) population associated with exposure to environmental contaminants (i.e., hazardous constituents).